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IDA PAPER P-1531

CONTINUING ISSUES (FY 1980) CONCERNING MILITARY USE OF THE SPACE TRANSPORTATION SYSTEM

Reinald G. Finke
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December 1980

Prepared for

Office of the Under Secretary of Defense for Research and Engineering

IDA

INSTITUTE FOR DEFENSE ANALYSES
SCIENCE AND TECHNOLOGY DIVISION

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The purpose of this study was to continue examination of DoD issues concerning military use of the Space Transportation System. Current issues are in the areas of Shuttle performance, spacecraft and Shuttle ground handling in the operational phase, Shuttle survivability, DoD space experiments and the use of man, advanced space technology and Shuttle launch costs. Principal findings in each of these areas were the following:

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D. DoD Space Experiments and the Use of Man. The Air Force Space Test Program (STP) is presently active in four areas: (1) experiment definition and integration, (2) Sortie Support System acquisition, (3) crew training, and (4) flight scheduling. Similarities with the NASA Spacelab program scheduled for a first launch a year before the first STP experiment in FY 1984 may provide useful examples in hardware and experience to help define and perhaps complement STP needs for facilities and procedures.

E. Advanced Space Technology. In attempting to identify new directions in technology for advanced military space missions in the Shuttle era, this study used two complementary approaches. One started from the possible classes of missions and moved through far-term trends to illuminate new technology directions, in order to supply bounds within which the new technology needs will be found. The other moved from imagined new mission "opportunities" to requisite technologies to supply more detailed examples. Actual specific technology requirements should become more evident after operational experience has been accumulated by the Shuttle and its crews. The Air Force is setting up the organizational machinery to associate users' requirements with technology development efforts and Shuttle operational experience.

F. Space Launch Costs. The growth in estimated Shuttle launch costs from 1972 to 1980 appears to parallel the growth in actual launch costs of expendable launch vehicles.

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December 1980

A

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400 Army-Navy Drive, Arlington, Virginia 22202
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A. Shuttle Performance. NASA is defining plans regarding means for improving the Shuttle performance to remedy by mid-1986 a payload deficiency of about 8000 lb for the Performance Reference Mission 4. While most of the planning activity to date has been devoted to examining thrust augmentation by addition of auxiliary solid or liquid rocket propulsion units, a number of other feasible options exist which involve modifying or uprating the present components of the Shuttle. A consensus of sources indicates that, if initial funding is committed in FY 1982 and suitable resources are applied to implementing enough of the options, NASA could produce the desired Mission 4 performance in time without resorting to thrust augmentation.

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EXECUTIVE SUMMARY

This study* continues previous IDA studies and analysis effort examining DoD issues concerning the Space Shuttle program and uses of the Space Shuttle vehicle. The objective was to assist the DoD by identifying, and suggesting possible means for resolving, issues involved in adapting DoD space missions to the Shuttle. Because of the broad scope of this task and the small level of effort authorized, it was conducted as an overview of the DoD program without examination of individual areas in detail. Reliance was made on available and developing relevant studies, other reference material and individual discussions with personnel at Headquarters USAF, the USAF Space Division, NASA Headquarters, Kennedy Space Center, Marshall Space Flight Center, Thiokol, The Rand Corporation, The Aerospace Corporation, Rockwell International, and Analytic Services Inc. The following subtasks (paraphrased from the Task Order) were included, with the nature and distribution of effort among them determined by the availability of relevant system and mission studies and other required reference information:

a. Shuttle Performance: examine NASA plans for improving the Shuttle performance to remedy the early payload deficiency for the Performance Reference Mission 4.

b. Spacecraft and Shuttle Ground Handling: review plans for logistics support and ground handling of payloads and the Shuttle in the operational phase to enable the Shuttle to achieve a flight

*Performed for the Office of the Director (Offensive and Space Systems), OUSDR&E, involving thirteen man-months of effort.

rate allowing timely launch of military payloads without compromising other users' scheduling requirements.

c. Survivability: review available studies of issues in determining and enhancing survivability in its impact on availability of the Shuttle for military missions.

d. DoD Space Experiments and the Use of Man: review plans for Space Test Program (STP) experiments regarding definition of experiments, crew training, and expanding the use of man, in the light of similar NASA Spacelab plans.

e. Advanced Space Technology: identify new directions in technology for advanced military space missions.

In addition, the cognizant office requested informally during the study that a brief comparison be made of space launch costs via the Shuttle and via expendable launch vehicles.

The principal observations on each of the topics are as follows:

A. SHUTTLE PERFORMANCE

While the initial Shuttle payload capability will be significantly short of the design performance, NASA has already authorized a number of modifications of the Shuttle components to improve the payload part way before the time the more demanding missions are scheduled. The current partial plans include lighter-weight Orbiters, a reduced-weight External Tank (ET), increased thrust for the Space Shuttle Main Engines (SSMEs), and several small improvements in the Solid Rocket Booster (SRB), all projected to be implemented before the end of CY 1983. The incorporation of these approved changes is expected to result in a Shuttle with a payload capability of 24,000 lb for the 98-deg, 150-nmi Mission 4, still 8,000 lb short of the 32,000-lb requirement. Unless further payload improvements are accomplished by CY 1986, the Shuttle will not be able to perform Mission 4 as desired.

A means of providing a significant payload increase with minimal impact on the design of the basic Shuttle components (at the price of apparent increased complexity, however) is via thrust augmentation, the addition of MX-first-stage-sized Strap-on Solid Motors (SOSMs) attached to the side of the SRBs or the addition of a Liquid Boost Module (LBM) composed of Titan Stage-1 engines and tanks mounted on the aft end of the ET. The SOSMs are calculated, in the IDA analysis, to add about 10,000 lb of payload but also to increase the maximum dynamic pressure to about 775 lb/ft^2 (about 95 lb/ft^2 beyond the 680 lb/ft^2 value projected as the limit from the associated structural stresses for flights subsequent to the fourth); the LBM is calculated to add about 14,000 lb with a "softer" ride, to a maximum dynamic pressure of about 635 lb/ft^2.

Other possible Shuttle payload improvement options exist (see Table II-5) that could offer some performance enhancement as alternatives to thrust augmentation, without adding components to the configuration. The feasible amounts of the continuous changes and a compatible combination of the options to add up to the desired 8000-lb increment have not been determined. Enough time is considered to exist by the organizations interrogated in this study--about five years after a mid-1981 decision date until the first desired flight availability--to implement any of the considered options. Relative risk assessments for the various options were not available in general for this study, but the discussion in the main text includes reservations gleaned from the available industry and government sources. Costs need further definition, and NASA and USAF studies are underway, to be completed in mid-1981.

This study concludes, from discussions with NASA, USAF, and contractors, that enough feasible Shuttle payload improvement options exist so that NASA could be able to produce the desired Mission 4 performance in time, provided initial funding can be committed in FY 1982 and suitable resources are applied. These available options, taken together, are of an aggregate size that could allow NASA by the early 1990's (spreading the necessary expenditures over a number of years) even to double the requested capability, if funding were made available.

B. SHUTTLE OPERATIONAL CONSIDERATIONS

Adoption by the Air Force of plans to provide an off-line payload-processing facility in the Solid Motor Assembly Building has transferred the concern for producing timely launch of military payloads from the payload-handling arena to the Shuttle launch-rate capability. Factors influencing Shuttle launch rate include Orbiter turnaround time and the availability of Shuttle components and processing facilities. A study by the Kennedy Space Center (KSC) Shuttle Turnaround Assessment Group (STAG) examined the impact of choke points such as Orbiter Processing Facility test bays, Vehicle Assembly Building integration cells, Mobile Launch Platforms, pads, and Orbiters, and determined that the achievable flight-rate capability may be only thirty per year in 1985. Incrementing any one of these elements does not achieve the desired forty flights per year, so attention must be focused on ways to reduce the time involved in ground processing procedures. Ongoing NASA/USAF studies are reviewing this turnaround-timeline problem.

Plans for the establishment of a logistic supply chain for support of the Shuttle in its operational phase are in preparation. Planning issues were reviewed at a Shuttle Logistics Support Conference held at VAFB in May 1980, and action items were assigned to specific organizations for clarification, amplification, or implementation. All major aspects pertaining to logistics planning appear to have been addressed.

C. SURVIVABILITY

Two studies were available for IDA review: one, completed in FY 1979, on Shuttle survivability by Rockwell International (RI) for the Space Division, and a second, in process into FY 1981, on Shuttle dependability by Rand Corporation for the Air Force; no new analysis by IDA has been added. The first considered the range of hazards to the Shuttle from electronic, communications, and ground disruptions to threats while in orbit. The second considered security risks and traffic constraints due to Shuttle fleet size, turnaround operations, and Shuttle reliability.

The RI study effort concentrated largely on ground operations. Its principal contribution was to identify vulnerable components in the logistics system, from sole-source suppliers, through critical transportation links, to launch facilities. Recommendations included broadening the manufacturing base, creating parallel transportation modes, and augmenting site security provisions. Some details of communications vulnerabilities were freshly illuminated, but considerations of survivability on-orbit presented no new hazards requiring responses significantly different from those outlined in IDA, 1977.

While survivability is a principal consideration in establishing the military utility of the Shuttle, other important factors with similar impact are availability and dependability. Rand, for instance, has expressed concern that the Shuttle will not be able to replace current expendable launch vehicles because it will not achieve the desired flight-rate capability, and that the presence of man will detract from the dependability of the system (in contrast with views of NASA, USAF, and DoD discussed elsewhere in this report). The crowded flight schedule of the Shuttle as strictly a delivery vehicle may preclude its use for exploiting the new capabilities originally envisioned, particularly payload return and manned tending. Supplementing the Shuttle with an unmanned Shuttle-derived launch vehicle is a route proposed by Rand to relax the Shuttle traffic demands and improve launch vehicle dependability; continuing expendable launch vehicles may be another. A Shuttle-derived launch vehicle would be prone to many of the same potential component failures that could cause a Shuttle stand-down, while current expendables would not. The topic of a "Survivable Military Launch System" is an area for further study.

D. DOD SPACE EXPERIMENTS AND THE USE OF MAN

The Space Test Program (STP) is to serve as a pathfinder to explore ways to use the Space Shuttle as a manned laboratory in space for DoD space experiments. At the present time STP is active in four areas: (1) experiment definition and integration, (2) Sortie Support System acquisition, (3) crew training, and (4) flight scheduling.

In the experiment definition area, the STP office fills an advisory and supporting role to assure that maximum advantage of the unique features of the Shuttle be taken in experimenters' plans. It also plays a major role in experiment integration, flight planning and ground operations. Experiment integration and the associated costs continue under study in an effort to discover ways to reduce manpower requirements and costs.

A Sortie Support System contractor was to be selected in CY 1980. This contractor is to furnish experimenters with necessary flight-support and training equipment, and services for integration, checkout, launch support, orbital support, and payload return. The degree to which NASA's Spacelab hardware and experience will be utilized by the winning contractor cannot be ascertained at the present time.

Principal activity in the crew training area is defining the specific role of the payload specialist and determining the type of training required and the degree of sophistication needed in training simulators. Inasmuch as the NASA Spacelab program has many similarities to STP, consideration is being given by USAF to the usefulness to STP of existing NASA facilities and procedures already set up to effect training for these missions. Unnecessary duplication in training facilities should be avoidable through this coordination.

Flight scheduling faces uncertainties in the Shuttle operational date and the Shuttle flight-rate capability. The first STP experiment is now scheduled for FY 1984. Concerns about saturation of Shuttle launch capacity with delivery missions may be alleviated by a proposed increase in the Shuttle fleet, improved turnaround operations, and reducing the effective utilization for Spacelab flights by shortening their duration and sharing time with other users to provide additional flight opportunities for other programs.

E. ADVANCED SPACE TECHNOLOGY

The presence of the Shuttle will allow improvements in military space systems to be derived from new technologies that can be developed in parallel with the Shuttle learning period. In attempting to identify the directions in technology that may be required to support or make feasible advanced military missions in space, dual approaches are utilized here to examine the spectrum of the U.S. military involvement in space and how it might be affected by new technological thrusts complementing the introduction of the Shuttle.

In one approach, characteristics of the four generic military space mission categories, i.e., observation, information transfer, logistics and defense, are noted in an IDA analysis. Identified are principal mission functions, the near-term means of implementation, far-term trends, and the broad technology thrusts that are likely to be the key contributors to realization of the far-term trends. This format is intended to supply bounds within which the new technology needs will be found.

In another approach, the Aerospace Corporation suggests the idea of a so-called "Architectural Sieve" to focus on those key technologies that must be available to support a new mission/performance capability, or "opportunity" in Aerospace terminology. Five example "opportunities" are examined: a system application (a global information/C^3 network), two support functions (space transportation and on-orbit operations), a building block (large space structures), and a system characteristic (survivability).

While these technology-identification schemes give some indication of the general direction of future technology thrusts (see Tables VI-1 and VI-2), the required knowledge of the nature of future missions in the Shuttle era, and hence of their specific technology requirements, may only become available after some operational experience has been accumulated by the Shuttle and its crews.

An important, albeit non-technical, consideration in focusing technology programs is the establishment of an effective communications scheme to coordinate determination of needs by operational organizations with technology development activities. The organizational machinery set up by the Space Division to achieve this end is described herein.

F. SPACE LAUNCH COSTS

The brief review of space launch costs reported in the appendix determined that the escalation in estimated Shuttle launch costs by a factor of about 3.5 from the earliest estimate in 1972 ($10.5M) to 1980 is essentially the same as that experienced with actual costs of expendable launch vehicles in the same period.

TABLE OF CONTENTS

FIGURES

TABLES

ABBREVIATIONS

ATM	Apollo Telescope Mount
ASAT	Anti-Satellite
DFRC	Dryden Flight Research Center
DoD	Department of Defense
ELV	Expendable Launch Vehicle
ESA	European Space Agency
ET	External Tank
ETR	Eastern Test Range
FMOF	First Manned Orbital Flight
FPL	Full Power Level (109% Thrust)
GLOW	Gross Liftoff Weight
GPS	Ground Processing Simulation
HTPB	Hydroxy-terminated polybutadiene
IDA	Institute for Defense Analyses
IOC	Initial Operational Capability
IUS	Inertial Upper Stage
KSC	Kennedy Space Center
LBM	Liquid Boost Module
MECO	Main Engine Cut-Off
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
OMD	Operational Maintenance Documents
OMS	Orbital Maneuvering Subsystem
OPF	Orbiter Processing Facility
OV	Orbiter Vehicle

PBAN	Polybutadiene acrylonitrile
RFP	Request for Proposal
RI	Rockwell International
SD	Space Division, Air Force Systems Command
SIMS	Shuttle Inventory Management System
SOFI	Spray-on Foam Insulation
SOSM	Strap-on Solid Rocket Motor
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
SSS	Sortie Support System
ST	Space Telescope
STAG	Shuttle Turnaround Assessment Group
STP	Air Force Space Test Program
STS	Space Transportation System
TPS	Thermal Protection System
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
ΔV	Velocity Increment

I. INTRODUCTION

This paper continues previous IDA studies and analyses (IDA 1977, IDA 1978 and IDA 1979) examining issues regarding the Space Shuttle program and uses of the Space Shuttle vehicle. The specified areas of interest for FY 1980 are the following:

Shuttle Performance. Examine the adequacy and timing of specific design modifications planned for the Space Transportation System in order to satisfy DoD spacecraft weight and schedule requirements.

Spacecraft and Shuttle Ground Handling. Briefly review progress on the development of plans for the ground handling of DoD payloads at KSC and VAFB from arrival at the launch site to installation in the Shuttle. Review plans for developing the logistic supply chain for support of the Shuttle in its operational phase.

Survivability. Review and critique available DoD, Service, or industry studies of vulnerabilities of the Space Shuttle and other spacecraft and proposals for enhancing their survivability.

DoD Space Experiments and the Use of Man. Review the preparations for DoD experiments to be conducted in conjunction with the Space Shuttle under the direction of the Air Force Space Test Program (STP). Areas to be considered in this review will be plans for crew training, plans for definition of STP experiments and plans for expanding the use of man. Compare these plans with NASA plans for similar activities.

Advanced Space Technology. Identify new directions in technology that may be required to support or make feasible possible advanced military missions in space.

Because of the comprehensive nature of these issues and the small level of effort authorized, the studies in general were conducted as overviews of DoD concerns without examination of individual areas in great detail. Reliance was made on available and developing relevant studies, other reference material and individual discussions with personnel at Headquarters USAF, the USAF Space Division, NASA Headquarters, Kennedy Space Center, Marshall Space Flight Center, Thiokol, The Rand Corporation, The Aerospace Corporation, Rockwell International, and Analytic Services Inc. However, the section treating Shuttle performance does contain a limited independent IDA analysis. Also included, as an appendix, is a brief analysis of projected Shuttle launch costs in relation to the historical and projected costs of expendable launch vehicles. This cost comparison was made because of concerns encountered in the Shuttle user community over escalating Shuttle launch costs.

II. SPACE SHUTTLE PERFORMANCE

A. INTRODUCTION

The payload delivery capability of the Space Shuttle will be considerably less than the design value for the first few flights with the Orbiter "Columbia" (OV-102), with the early External Tank (ET), and with the thrust of the Main Engines (SSMEs) at 100 percent or Rated Power Level (RPL). For example, the initial capability in CY 1981 is projected to be only 36,800 lb (versus the specification of 65,000 lb) for an east-launched ETR mission into a 28.5-deg-inclination 150-nmi-altitude circular orbit for a two-man crew and a one-day duration (the initial plateau for the mission shown in Fig. II-1a). However, Fig. II-1a shows a number of approved Shuttle-uprating changes aimed at increasing the payload capability for this mission to the specified 65,000 lb by the end of CY 1983. A continuation of Fig. II-1a, starting at the time (mid CY 1984) Initial Operational Capability (IOC) is planned for Vandenberg Air Force Base (VAFB), is shown in Fig. II-1b for a mission into a 98-deg, 150-nmi orbit for a two-man, one-day flight.

The most stressing mission is called Mission 4 (see IDA, 1978), for planning purposes projected to be launched in CY 1986 from VAFB to deliver a gross payload weight of 32,000 lb into a 98-deg-inclination 150-nmi-altitude circular orbit and to rendezvous with and retrieve a 25,000-lb spacecraft, using a four-man crew for seven days. Note from comparison of OV-103 performance in CY 1984 in Figs. II-1a and b that a 31,300-lb payload into a 98-deg, 150-nmi orbit from VAFB is equivalent for the Shuttle to 68,300 lb into a 28.5-deg, 150-nmi orbit from ETR for two man-days in orbit. In addition, Mission 4 specifies increments in orbital

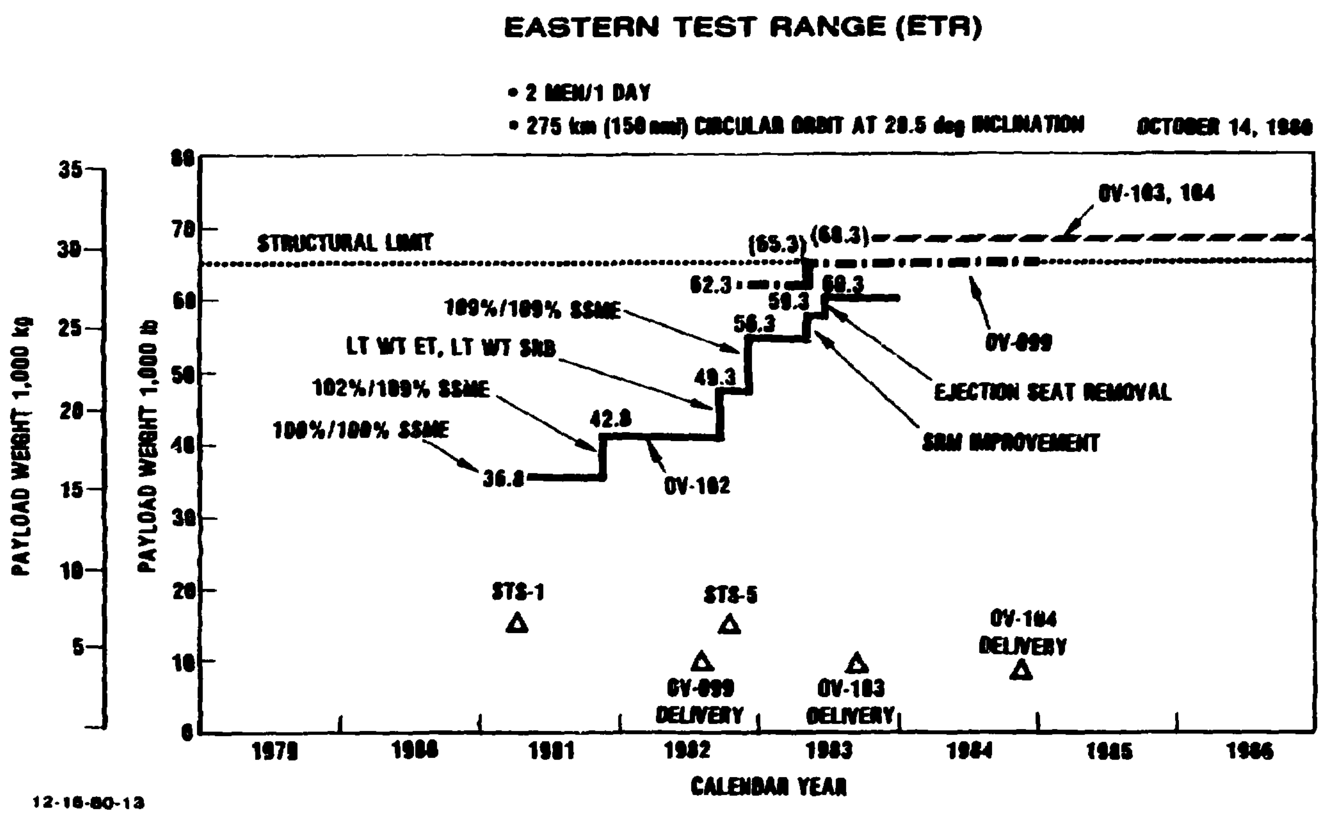


FIGURE II-1a. Space Shuttle Capability Evolution (Courtesy NASA)

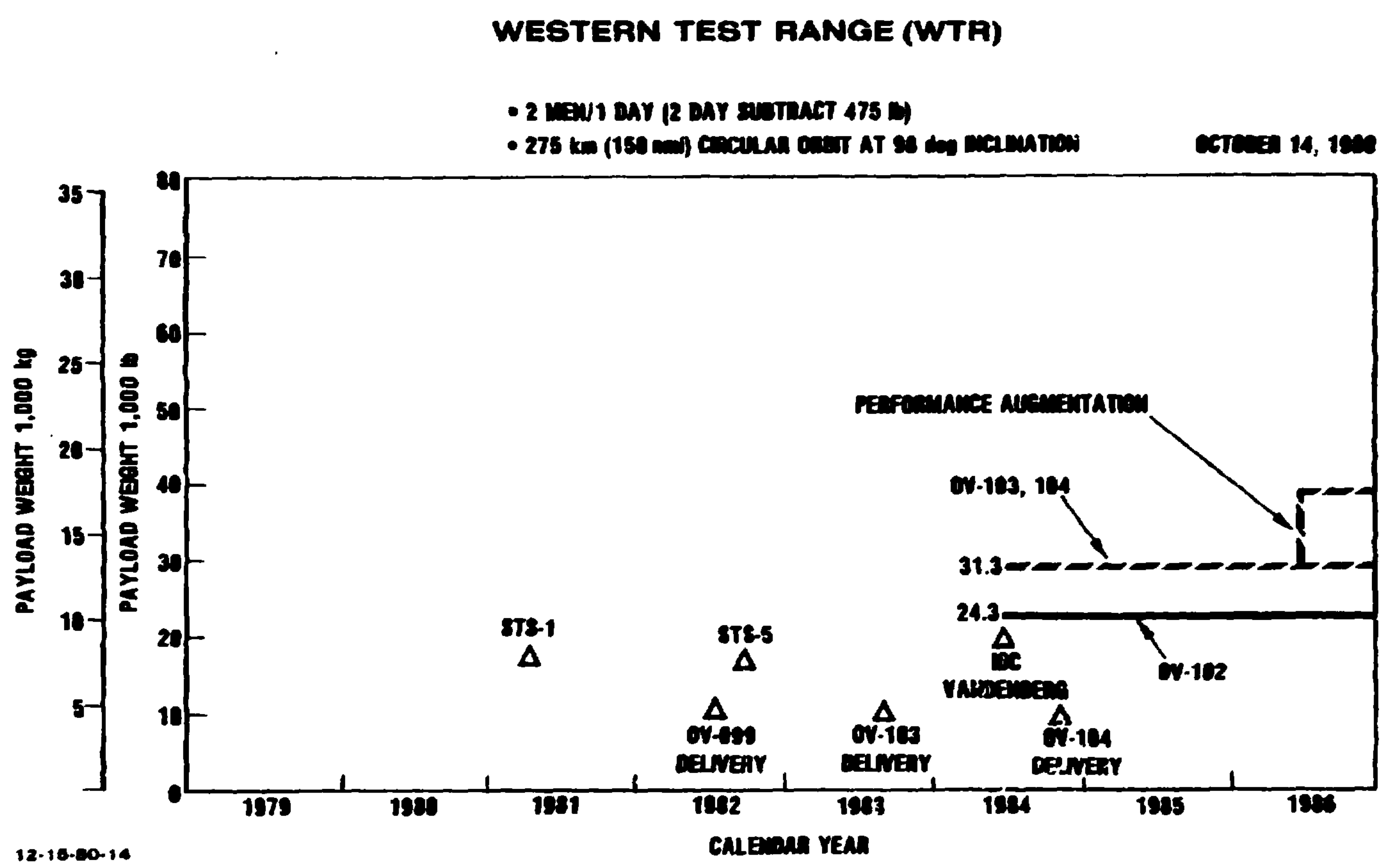


FIGURE II-1b. Space Shuttle Capability Evolution (Courtesy NASA) maneuvering requirements and mission duration over the missions represented in the figures; these increments are equivalent to an additional 5,000 to 10,000 lb of required payload. Therefore, it should be noted that the 32,000-lb Mission 4 with its other requirements is more demanding by 10,000 to 15,000 lb (of equivalent east-launched payload) than a 65,000-lb 2 man/1 day east-launched mission.

The modifications shown in Fig. II-1a will be insufficient to satisfy the Mission 4 requirements. Further performance augmentation (depicted schematically in CY 1986 in Fig. II-1b) will be required to achieve the desired capability. This mismatch between Shuttle capability at VAFB and Mission 4 requirements is of continuing concern to DoD; NASA is intensively studying means to provide performance augmentation and the USAF is reviewing mission requirements.

The planned (approved) uprating changes include lighter-weight Orbiters (OV-099 and OV-103), weight reduction in the ET, increase in SSME thrust to Full Power Level (109 percent of the thrust at RPL), and some SRB changes involving a small increase in burn rate, a nozzle extension, a reduction in case weight, and modifications in the inhibitor to achieve an improved thrust profile.

Performance (thrust) augmentation options receiving principal attention by NASA in the past year are Strap-on Solid Motors (SOSMs) attached to the side of the SRBs and the Liquid Boost Module (LBM) composed of Titan Stage 1 engines and tanks mounted on the aft end of the ET.

Other options considered in IDA studies during the past year can be grouped into three classes: (1) continuous incremental changes whose benefit will be sized by a future tradeoff or by a to-be-determined reduction in some safety factor, (2) discrete changes with major influence (greater than 5000-lb payload improvement, say), and (3) discrete changes with minor influence. In class 1 are reduced on-orbit ΔV requirement, decreased SRB burn time, further increased SSME thrust, increased

ET capacity, reduced drag during boost, thinner TPS (thermal protection system) for the Orbiter, and reduced insulation on the ET. Under major discrete changes are a composite case for the SRBs, composite material for Orbiter structure/TPS, and replacement of PBAN* with HTPB** propellant in the SRBs. Minor discrete changes are optimum expansion-ratio SRB nozzles, composite material for Orbiter control surfaces, elimination of the helium purge requirement for SSME turbopump bearings, elimination of SRB recovery systems, and removal of the 3-g limit on SSME thrust.

This chapter discusses the payload improvements from these options, their technological feasibility, and compromises to be considered. Other viable options not discussed here, but not rejected either, are slush propellants for the ET, fluid (e.g., hydrogen or ammonia) injection in the SRBs, tapered mixture ratio for the SSMEs, and in-orbit storage of on-orbit consumables and subsystems, such as propellants, power modules, and Spacelab modules.

B. PLANNED UPRATING CHANGES

1. Orbiter

For the Orbiters, the weight reductions planned, their date of implementation, and the effect on performance are as follows (from Fig. II-1a):

Item	Payload Gain (lb)	Planned date
Ejection seat removal (OV-102)	1,000	May 1983
Introduction of OV-099 (vs. 102)	5,000	Nov 1982
Introduction of OV-103 (vs. 102)	8,000	Dec 1983

2. External Tank (ET)

Figure II-2 depicts the general features of the External Tank as currently constructed. Not detailed, however, is the

*Polybutadiene acrylonitrile.

**Hydroxy-terminated polybutadiene.

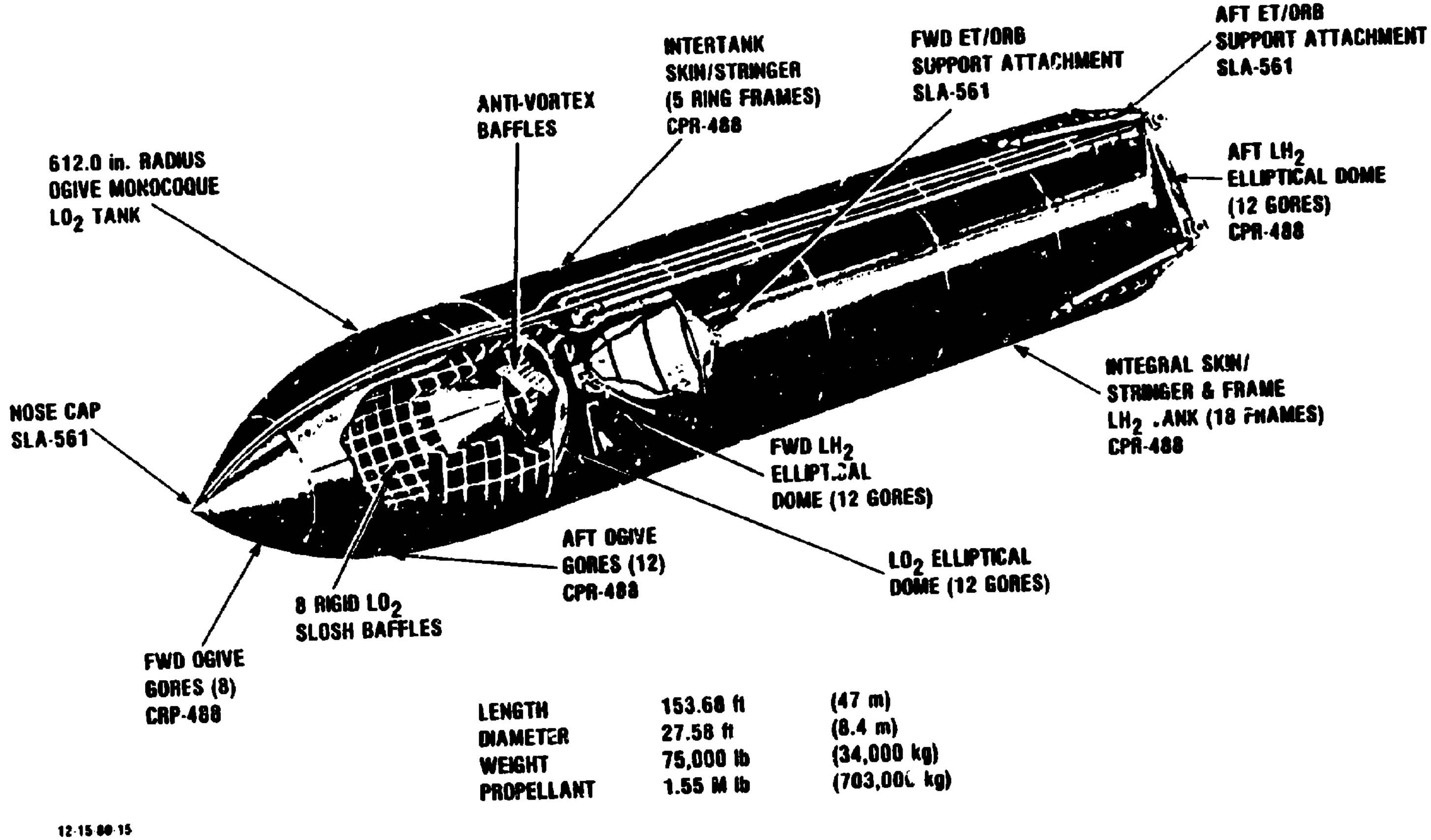


FIGURE II-2. Space Shuttle External Tank (Courtesy MSFC)

SOFI (Spray-on Foam Insulation) that must be added to provide extra-safe thermal protection during the ascent phase of the early flights. This insulation brings the total weight of the empty heavyweight tank to 78,000 lb. The weight of the lightweight tank is expected to be reduced to 72,666 lb, permitting an increase in Shuttle payload capability essentially equal to the tank weight reduction. Further tank weight reduction due to reduction in SOFI may become possible as flight experience resolves the thermal protection uncertainties.

The lightweight external tank is to be achieved by structural weight reduction in the hydrogen tank, the oxygen tank, the intertank and other items. As an example, Fig. II-3 shows the nature of the changes planned for the hydrogen tank. The factor of safety for axial and time-consistent (i.e., repeatable) loads is being reduced from 1.4 for the early tank to 1.25 for the lightweight tank, thus permitting a reduction in structural reinforcement members and a reduction in weight. This reduction is made possible as a result of an extensive analytical and experimental loads investigation conducted at MSFC on a tank containing liquid hydrogen to produce a true thermal environment that would result in realistic stress-strain determination.

The fabrication schedule for the external tank has recently been changed to allow the introduction of the lightweight tank earlier in the flight schedule. (At one time the lightweight tank was ET-26; in 1979 it was advanced to ET-11.) As of November 1980 (NASA, 1980e), NASA's plan is to use the lightweight tank (as ET-7) beginning with the first operational flight, STS-5, now scheduled for September 1982. Early introduction of the lightweight tank is desirable because it allows an increase in Shuttle payload of about 6000 lb.

3. Space Shuttle Main Engine (SSME)

Technical problems in the development of the main engine have plagued the Shuttle program for several years. The

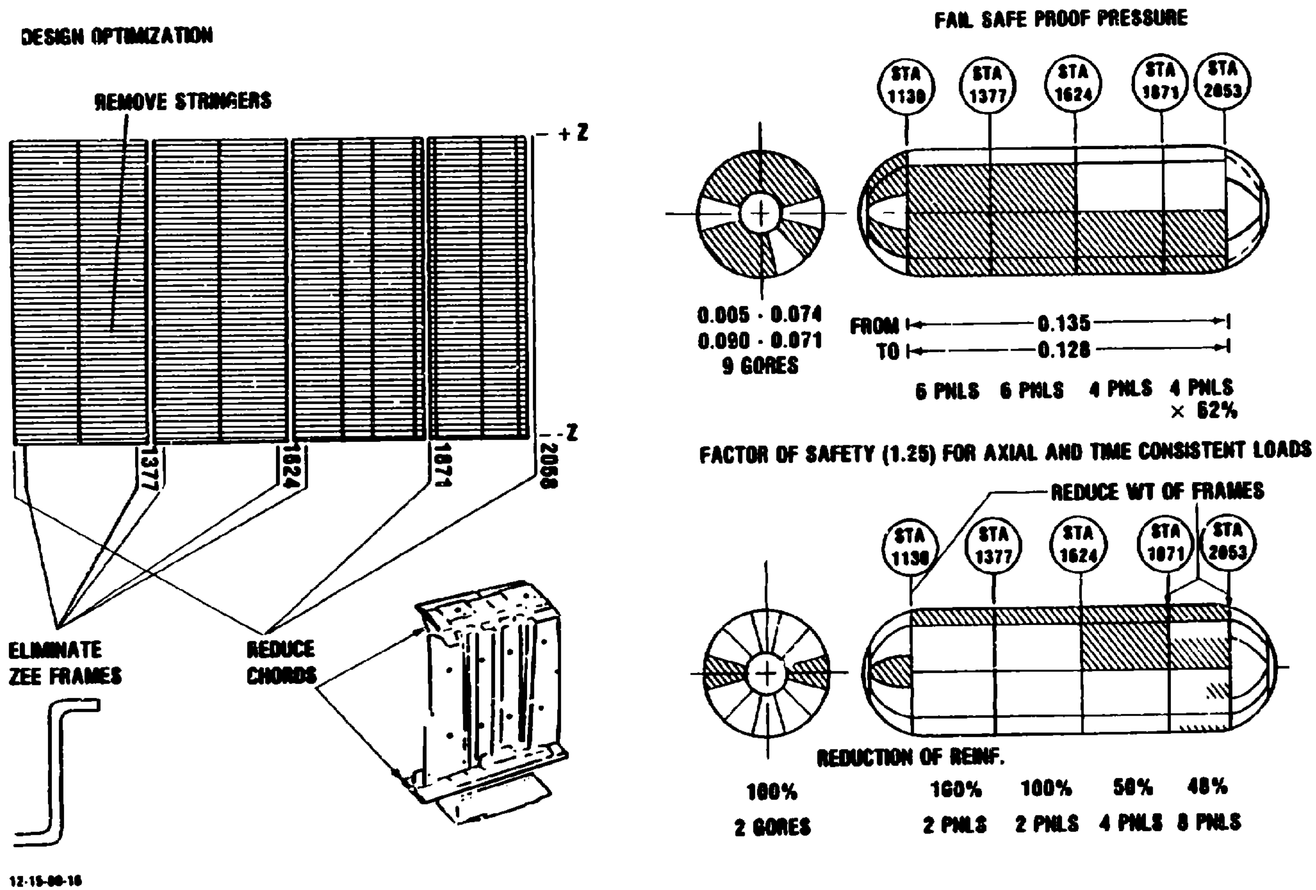


FIGURE II-3. Areas for External Tank LH_2 Tank Weight Reduction (Courtesy MSFC) principal difficulties associated with the high pressure compressor components of the SSME appear to have been overcome. In June 1980 the accumulated total test time toward certification of the SSME for STS-1 reached the 80,000-sec goal; as of November the total test time had exceeded 94,000 sec, with more than 56,000 sec at or above Rated Power Level (RPL) or 100 percent thrust, and with more than 1000 sec at Full Power Level or 109 percent thrust. Certification tests are continuing at power levels of 102, 104 and 109 percent. In addition, over 7,5[illegible] sec of time have been accumulated in the main propulsion test stands where all three engines operate in the clustered arrangement of the operational Shuttle. The first four flights are to be flown at 100 percent thrust for both nominal-ascent or abort conditions. Subsequent flights schedule availability of 109 percent thrust for abort conditions. Beginning with the first operational flight STS-5 in September 1982 and continuing through STS-10 in June 1983, NASA's current plan (NASA, 1980e) specifies 102 percent thrust and 109 percent thrust for the nominal-ascent and abort conditions, respectively. Beginning with STS-12 in August 1983 the plan specifies 109 percent thrust (FPL) for both nominal-ascent and abort trajectories. NASA is currently modifying the engine program at the National Space Technology Laboratories, Bay St. Louis, Mississippi and Santa Susana, California, to certify the production engines for those thrust ratings. Major engine design changes now incorporated into production engines to support the use of FPL for nominal-ascent are listed in Table II-1. Engine operating parameters associated with these changes are tabulated in Table II-2 along with the values for the early production SSMEs to be used for the first manned orbital flight (FMOF) scheduled for March 1981.

TABLE II-1. MAJOR SSME DESIGN CHANGES FOR FPL CAPABILITY (COURTESY MSFC)

COMPONENT	CHANGE
Hot Gas Manifold	• Improved entrance conditions on inlet to 903 transfer tubes.
Fuel Preburner Injector	• Drill holes in fuel injector to improve preburner temperature balance
Low Pressure Fuel Turbopump	• 13 vane housing plus orificed turbine flow
Main Combustion Chamber	• Nickel-plated combustion chamber
High-Pressure Fuel Turbopump	• Second stage EDM slots and precision dampers on blades
	• Improved control of turbine end pilot
	• Bearing spring change
	• Bellows shield improvement
High Pressure Oxidizer Turbopump	• Helium purge system to reduce requirements to 100-150 SCFM
	• Carbon for both turbine seals
	• Bearing changes for clearances and springs
	• Haynes tips on 316L posts for outer 3 rows
	• Redesigned shield to protect row 12 from direct impingement
Nozzle	• Thick tubes
Low Pressure Oxidizer Turbopump	• Improved thrust bearing life
Main Oxidizer Valves	• New inlet sleeve which incorporates shim
Fuel Flowmeter	• Improved flow guide and straightener vanes

TABLE II-2. SSME OPERATING PARAMETERS (COURTESY MSFC)

	FMOF ENGINE		109/109 ENGINE
	RPL	FPL	
MCC Chamber Pressure (PSIA)	2,995	3,265	3,265
Low-Pressure Fuel Pump Speed (RPM)	15,300	16,200	15,770
Low-Pressure Oxidizer Pump Speed (RPM)	5,160	5,465	5,420
High-Pressure Fuel Pump Speed (RPM)	34,540	36,600	36,340
High-Pressure Fuel Pump Turbine Discharge Temp (R)	1,742	1,822	1,730
High-Pressure Oxidizer Pump Speed (RPM)	27,880	29,860	29,700
High-Pressure Oxidizer Pump Turbine Discharge Temp (R)	1,282	1,337	1,430

4. Solid Rocket Booster (SRB)

The approved solid rocket motor performance improvements to be introduced at different times are a one-percent propellant-burn-rate increase, a nozzle extension to increase the specific impulse, a reduction in the case weight, and some inhibitor modifications to achieve an improved thrust profile. The plan is to introduce the propellant-burn-rate increase in time for flight STS-3 (December 1981) with a consequent payload gain of 1000 lb. The other modifications are being considered for introduction for STS-5 and STS-9 (continuing thereafter). While the overall payload gain from both steps is expected to be 3000 lb, information from NASA (NASA, 1980d) indicates that this future improvement will just offset unexpected performance decrements recently discovered elsewhere, to give an eventual net gain of zero. A summary of the contemplated changes in motor characteristics for the two steps is given in Table II-3. (The SRM-design designation convention is the date of the design introduction, i.e., the 340th day of 1979, or 340-79.) The thrust profiles before and after these changes are shown in Fig. II-4.

Some modifications to the launch mount design at VAFB will be required to accommodate the new nozzle (increased from 7.16 to 7.60:1 expansion ratio) because of its increased length and exit diameter. It is understood that these modifications in the VAFB plans are being made. The larger size is the maximum compatible with existing KSC facilities.

C. REQUIRED PAYLOAD IMPROVEMENT

The latest available NASA determination (NASA, 1980d) of the payload capability of the Space Shuttle for Mission 4 is essentially (but not precisely) the same as one dated May 22, 1979 (Table II-4), which shows the payload with different SSME thrust levels, with and without the then-favored SOSM thrust augmentation

TABLE II-3. APPROVED SOLID ROCKET MOTOR PERFORMANCE IMPROVEMENTS (COURTESY MSFC)

PERFORMANCE SUMMARY

	STS-2	STS-3 and STS-4	STS-5, STS-9, et seq.
	MSFC-340-79 (QM)	MSFC-86-80 (Δr_b = 1%)	HPM (DESIGN MODS)
PAYLOAD GAIN (lb)	-REF-	1,000	3,000
SRB IGNITION WGT (lb)	1,295,277	1,293,338*	1,290,331**
PROPELLANT LOADED (lb)	1,107,127	1,107,127	1,107,127
VACUUM THRUST @ t = 2 s (lb)	2,908,100	2,955,400	3,081,800
MEAN EFFECTIVE OP PRESS (PSIA)	950	965	1,000
VAC ISP (sec)	265.4	265.4	268.4
BURN RATE @ P_c = 625 PSIA (ips)	0.364	0.368	0.364
INITIAL D_t (in.)	54.43	54.43	53.86
INTIIAL D_e (in.)	145.64	145.64	149.64
NOZZLE EXPAN. RATIO	7.16	7.16	7.72

*DEVELOPMENT FLIGHT INSTRUMENTATION DELETED

**LIGHTWEIGHT CASE-Δ 3350 lb

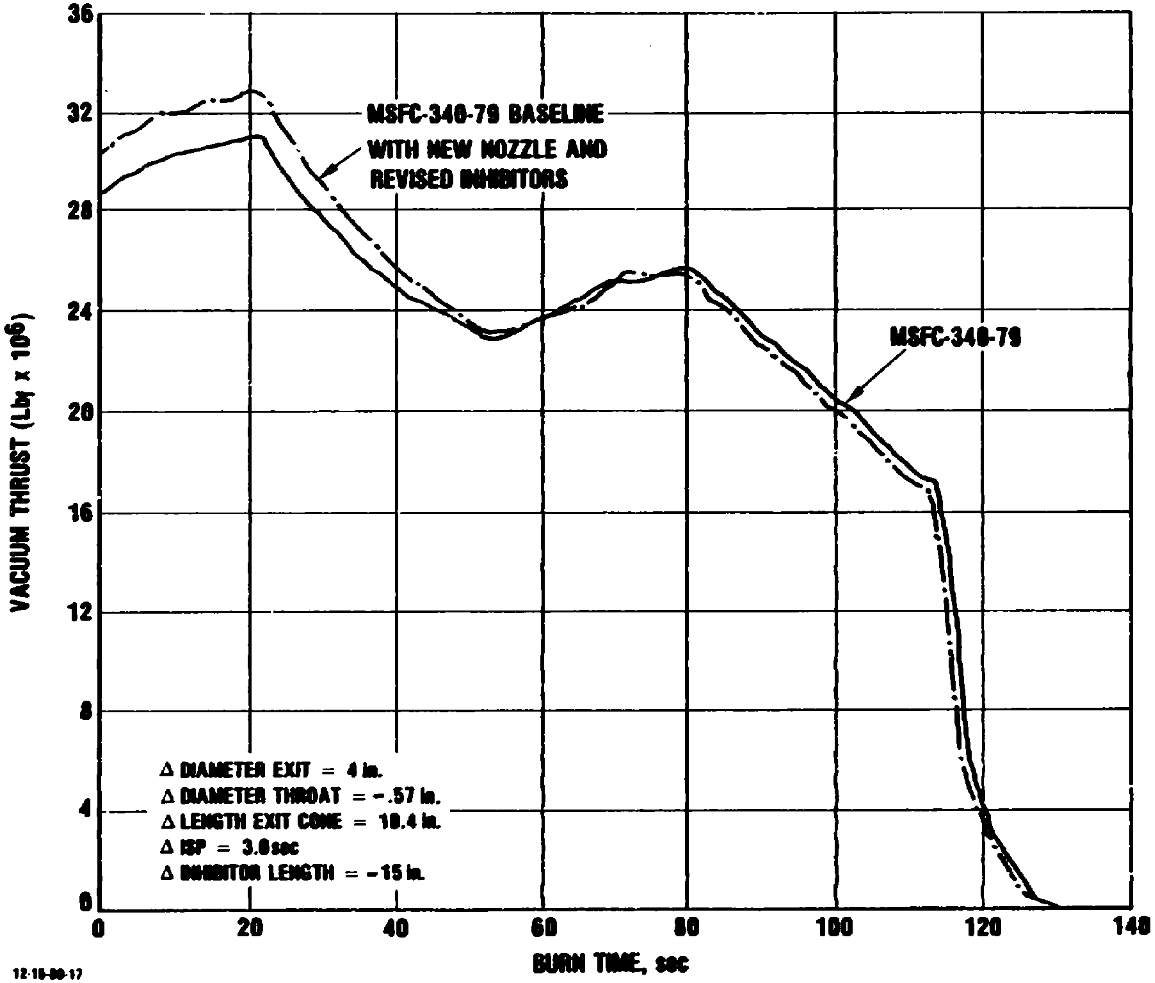


FIGURE II-4. Solid Rocket Motor Performance Enhancement (Courtesy MSFC) option, and for the baseline and possible alternative missions under consideration by the Air Force. The payload capability for the baseline mission with OV-103, the lightweight ET, and the 109-percent-thrust SSME for the nominal flight profile, without thrust augmentation, is given in the table as 24,000 lb, or 8000 lb less than the requirement of 32,000 lb.

TABLE II-4. PERFORMANCE REFERENCE MISSION 4 (Courtesy NASA) (Payload Capability, lb) May 22, 1979

THRUST LEVEL NOMINAL/ABORT	BASELINE		ALTERNATES			
	4-MAN/7-DAYS		4-MAN/4-DAYS (2)		2-MAN/3-DAYS (3)	
	W/O T.A.	W/T.A. (1)	W/O T.A.	W/T.A.	W/O T.A.	W/T.A.
109%/109%	24,000	32,000	27,000	35,000	32,200	40,200
100%/109%	16,000	24,000	19,000	27,000	24,200	32,200
100%/100%	11,500	19,500	14,500	22,500	19,700	27,700

NOTE: OV-099 2,000 lb less capability than OV-103
OV-102 5,000 lb less capability than OV-103

NOTE:
(1) SRB Strap-on Thrust Augmentation Option
(2) Deploy and Retrieve
(3) Deploy Only

The remainder of this chapter discusses the principal options available to make up this deficiency.

D. PROPOSED UPRATING OPTIONS

Proposals for different uprating options originate in different organizations and culminate in a value of the increase in Shuttle payload, which is based on ground rules that are generally not described in enough detail to allow satisfactory comparison. Furthermore, measures of the differences in flight loads associated with the vehicle changes made to improve payload are not always available.

The payload performance of the Shuttle is particularly sensitive to the acceleration in the early phases (the first minute or two) of flight when the component of gravity in the direction of the velocity vector is nullifying a major part (~60 percent) of the thrust force ("g-losses"). Generally, any vehicle change (lighter weight or greater thrust) that increases the early acceleration will lead to a payload increase. However, an increase in the early acceleration also increases the vehicle velocity as it traverses the dense lower atmosphere. The Shuttle, flying at a velocity V through air with an ambient density ρ, experiences a dynamic pressure ($q = 1/2\ \rho V^2$) that exerts forces on the structural members joining its components. While the velocity is increasing the density is decreasing, so the "q" passes through a maximum; the maximum "q" for the Shuttle (in the range 500 to 1000 lb/ft^2) occurs at a time 50-60 sec after liftoff at an altitude of about 25,000 ft and a speed of about 1000 ft/sec. The required strengths (and therefore weights) of some Shuttle members are set by the stresses created by the max q; a Shuttle structural design can be characterized by the greatest max q that it can withstand. Additionally, the stresses generated at max q depend on the vehicle attitude at the time of max q; the pitch and yaw angles should be kept close to null values at that time. Structural limits define a greatest allowable max q value of 819 lb/ft^2; allowances for possible excursions in atmospheric density, flight path, and attitude reduce the greatest allowable max q on a nominal ascent trajectory to about 650 lb/ft^2. Selection of time of launch based on favorable local weather and careful control of flight path and attitude, as well as structural strengthening, can be used to increase the allowable max q on a nominal ascent trajectory.

In order to provide a common assessment of the uprating options based on internally consistent calculations of the payload increment and its generally accompanying increase in flight loads (in terms of the increase in max q or in acceleration), this study made use of the IDA RANGE trajectory program, run on the IDA CDC 6400 computer, to calculate Shuttle performance.

For the trajectory program inputs, the assumed weights for the baseline Space Shuttle for Mission 4 were as follows:

		Weights in 1000's of lb	
Orbiter + SSMEs		170.3	207.1
OMS, RCS, Personnel, Mission Kit, etc.		36.8	
SRB:	propellant	2,214.3	2,580.7
	inert	366.4	
ET:	propellant	1,563.5	1,642.3
	inert	78.8	
GLOW (less payload			4,430.1

Propulsion thrust and specific impulses were taken as

	vacuum thrust (lb)	vac. I_{sp} (sec)	S.L. I_{sp} (sec)
SRB(ea)	3,300,000 (max)	268.4	245.9
SSME(ea)	512,300 (FPL)	455.4	375.3

The normalized thrust-time profile for the SRB (an approximation to the dash-dot curve in Fig. II-4) was taken as

time(t/t_{burn})	thrust (T/T_{max})
0.000	0.939
0.179	1.000
0.407	0.706
0.925	0.673
1.000	0.000

With these specifications, the SRB burn time was 119.95 sec.

The trajectory integration was carried out for an optimum pitch rate from SRB jettison through insertion into a circular orbit at 55-nmi altitude for a non-rotating earth (i.e., neglecting the earth's surface velocity), using the SSMEs all the way to insertion, throttled to 3-g maximum acceleration. While this orbit destination is not quite the 98-deg 150-nmi Mission 4 orbit, the results were used to determine the payload differences due to vehicle changes from the baseline vehicle, and the absolute payload was not at issue.

With these inputs the baseline vehicle (to be flown first on STS-18) is calculated to experience a max q of 654 lb/ft^2. NASA has set progressive limits (JSC, 1980) on max q from structural considerations for the different flights as follows:

Flight	max q(lb/ft^2)
STS-1	580
STS-2	620
STS-3,4	650
STS-5 to 16	680

1. Thrust Augmentation

While thrust augmentation options are currently under intensive study at NASA and the study will not be completed until mid-1981, it is nevertheless informative to examine the results of some recent estimates by NASA and IDA of potential performance gains afforded by the most attractive options (Figs. II-5 and II-6).

The favored thrust-augmentation option concurrent with the May 22, 1979 determination of the Shuttle's Mission 4 payload capability in Table II-4 was composed of a 90- to 115-in-diameter solid-rocket motor with 100,000-170,000 lb of propellant, strapped on to the side of each SRB (Strap-On Solid Motor, or SOSM, Fig. II-5). The payload increment for Mission 4 with use of the SOSMs was given by NASA variously as 8000 lb

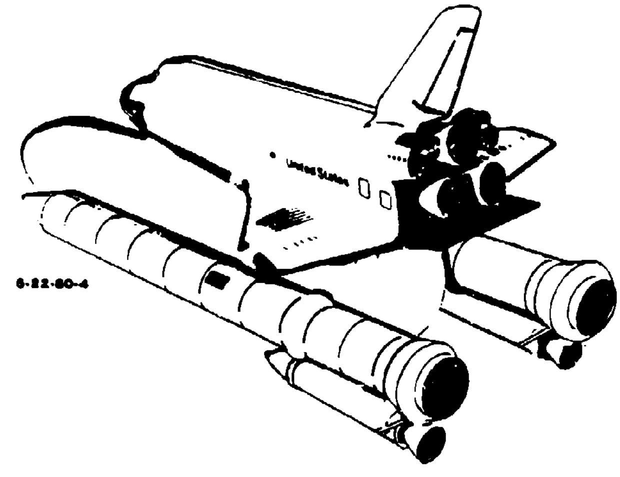


FIGURE II-5. Strap-On Solid Motors (SOSM)

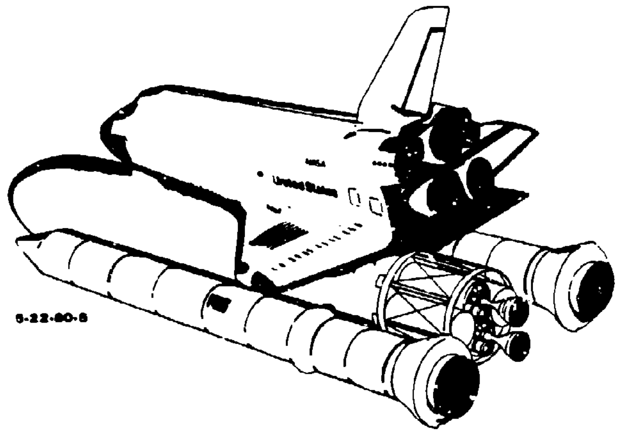


FIGURE II-6. Liquid Boost Module (LBM)

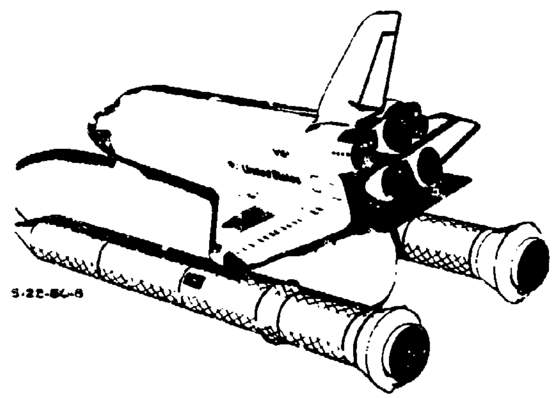


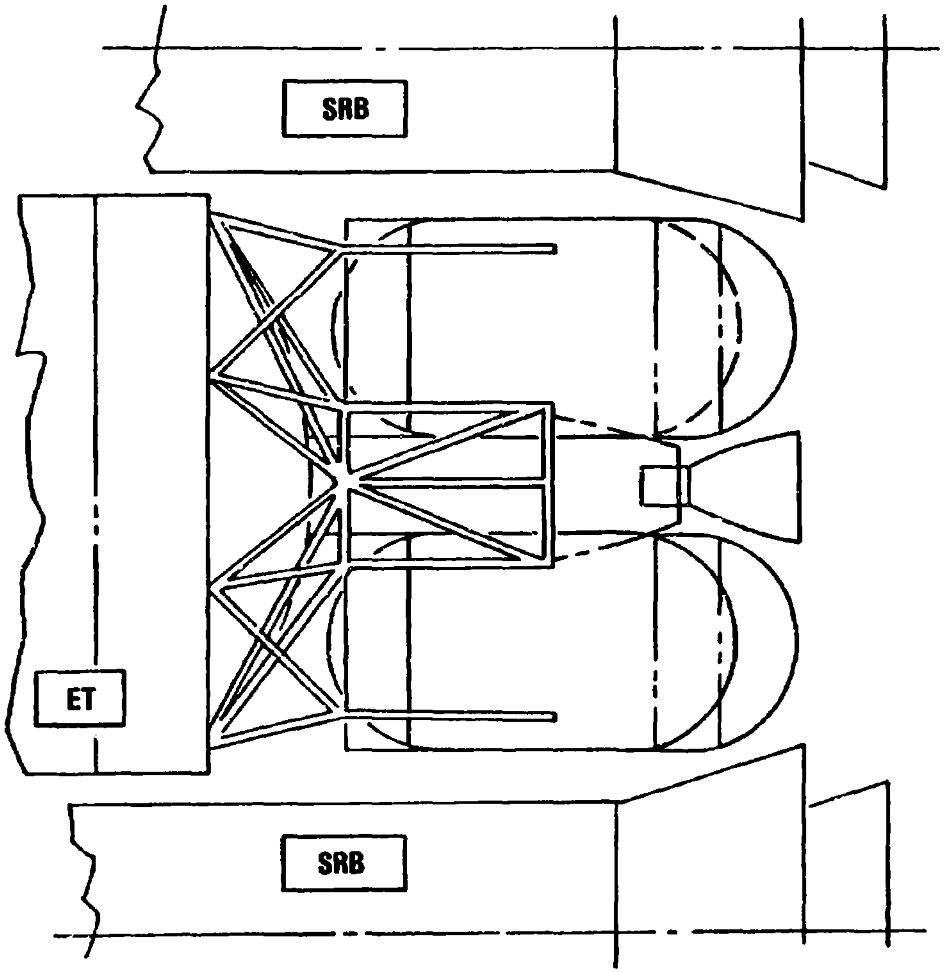
FIGURE II-7. Fiberglass-Case Solid Rocket Boosters

(Table II-4) to 9300 lb (NASA, 1979b), with an associated max q of 700 lb/ft^2. IDA calculations indicated an increment of 10,200 lb with a max q of 697 lb/ft^2 (with the 340-79 SRM--Table II-3). With the HPM SRM the max q becomes 775 lb/ft^2 for the same payload increment.

In November, 1979, NASA proposed (NASA, 1979b) the Liquid Boost Module (LBM, Fig. II-6) as the baseline thrust augmentation system. The LBM is to be composed of a Titan III Stage 1 rocket engine (two chambers) and four 10-ft-diameter tanks, two each for the N_2O_4 oxidizer and Aerozine-50 fuel, mounted on the aft end of the ET. The LBM would be ignited 5 sec after liftoff, would burn for 200 sec, and would be jettisoned with no planned recovery. The LBM airborne configuration is shown in Fig. II-8 and an exploded view of the LBM components is presented in Fig. II-9. NASA estimates of the resulting payload increment for Mission 4 vary from 16,000 lb (MSFC, 1980a) to 12,600 lb (NASA, 1979b). The latest NASA figure is 14,000 lb (NASA, 1980e). IDA trajectory calculations with 350,000 lb of LBM propellant indicated a gross payload increment of 16,500 lb, which becomes a net payload increment of 14,600 lb with the estimated (Aerojet, 1979) ET scar weight* of 1900 lb; the IDA calculated max q was 635 lb/ft^2 (with the HPM SRM).

The LBM non-recurring cost estimate presented in NASA, 1979b was $343M (1980$), compared there with an estimates SOSM non-recurring cost of $324M. The recurring cost estimate (MSFC, 1980) was $14M (1980$) without some of the costs of the sssembly and checkout procedures. The SOSM was estimated (NASA, 1979b) to have a launch cost $3M less than the LBM. An IDA estimate for the LBM scaled from a Titan III-D launch cost of $70M (1980$) is $22.5-$25M, assuming the LBM would cost the same as a Stage I. The need for further analysis is indicated to establish the costs adequately for comparison with other options giving similar payload improvement. The schedule for the LBM (MSFC, 1980a)

*Weight of LBM attach points on the ET that remain with the ET when the LBM is jettisoned.



- 4 Titan-Type 10' Diameter Tanks
- Titan Autogenous Pressurization Augmented with Helium
- Titan Stg I Engines/Truss
- Titan Stg I Boattail
- New Support Truss Ties Titan Elements to Separable ET Skirt
- Dry Weight 32K lb
- 350K lb N_2O_4/A-50 Usable
- Loaded Weight 385 K lb
- LBM Assy Length 24.2 ft Below LH_2 Dome (34.6 ft Overall)

FIGURE II-8. LBM Airborne Configuration (Courtesy MSFC)

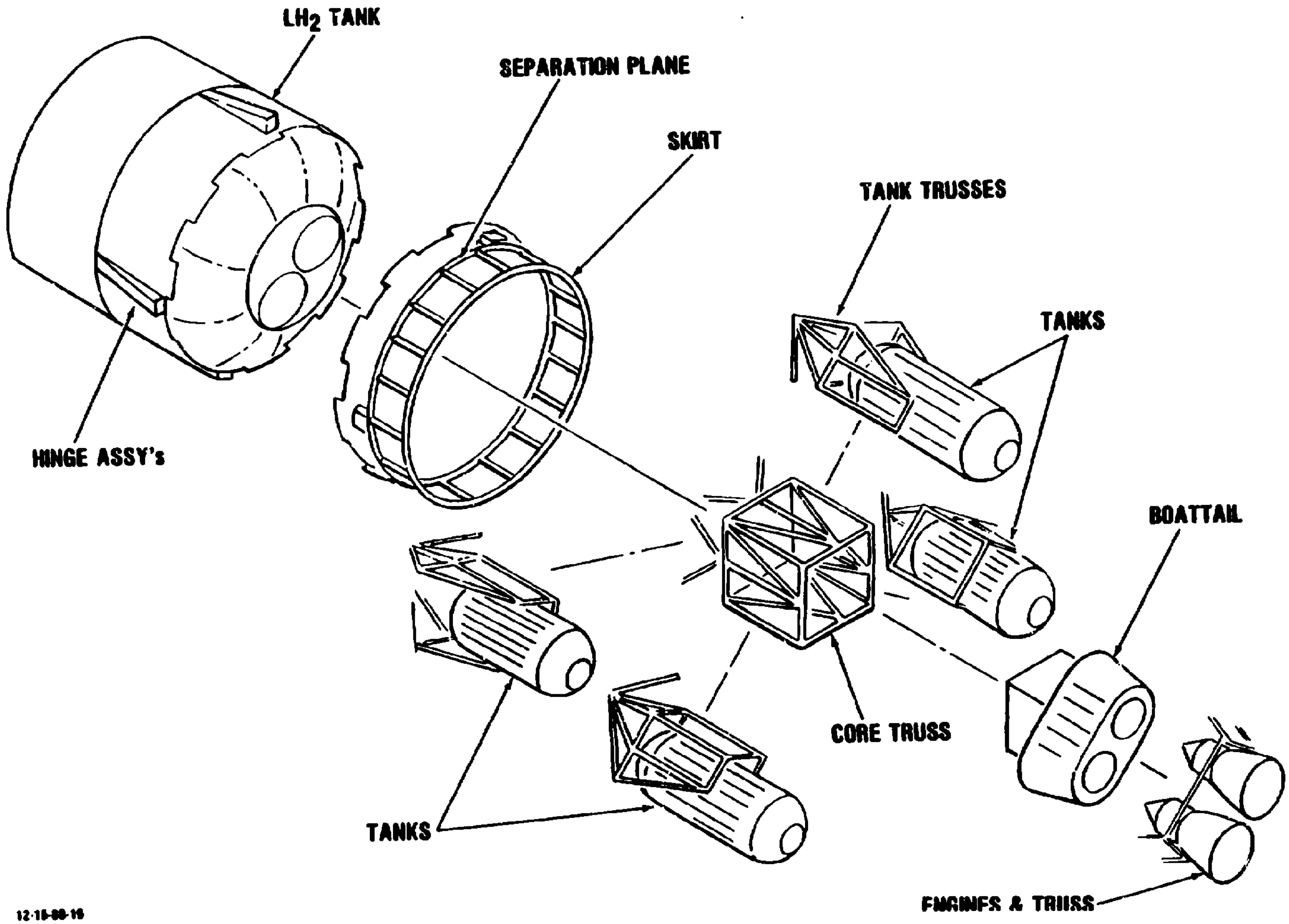


FIGURE II-9. Liquid Boost Module Components (Courtesy MSFC) showed a first launch in mid-CY 1985. The LBM augmentation is planned for flights at VAFB only. The LBM is in the study phase, with resolution of its further status planned to occur in mid-FY 1981 (NASA, 1980c).

2. Other Payload-Improvement Options

A number of other payload-improvement options exist as alternatives to thrust augmentation, some of which were considered in the deliberations that led to the adoption of thrust augmentation as the favored up-rating mode. One of the more persuasive arguments for thrust augmentation via strap-on solids or an appended liquid boost module was that either would perturb the design of the basic Shuttle components only in a peripheral way at a time when the main concentration of effort had to be applied to assuring that the existing design could successfully perform the Shuttle's First Manned Orbital Flight (FMOF). With FMOF scheduled for March 1981, much of the design review process has been completed and elements of the design team have become available to take a more critical look at those payload-improvement options that involve extensive modifications to existing components. Also some motivation to reexamine alternatives is coming from adversary arguments that thrust augmentation by adding components will result in even greater complexity for a configuration that is viewed as already being too complex.

The principal options for payload improvement, including thrust augmentation and modifications to the basic Shuttle components, are listed in Table II-5 along with the size of the potential reward in payload improvement obtained from IDA calculations, except as noted. The payload improvement for the continuous changes is given in terms of a partial derivative (1) with respect to the variable, and for the discrete changes (2 and 3) as the step increase in payload. (It should be noted that in some trajectory calculations where more than one change

TABLE II-5. POSSIBLE SHUTTLE PAYLOAD IMPROVEMENT OPTIONS

		Size of Reward (ΔPL)	Change for + 8000 lb
1.	Continuous Changes (partial derivatives)		
a.	Reduced On-Orbit ΔV Requirement	25 lb/ft/sec	-320 ft/sec
b.	Decreased SRB Burn Time (Increased Thrust)	615 lb/percent	-(+)13 percent
c.	Increased SRB I_{sp} (and Thrust)	2230 lb/percent	+4 percent
d.	Decreased SRB Inert Weight	340 lb/percent	-24 percent
e.	Increased SRB Propellant Weight (and Thrust)	1380 lb/percent	+6 percent
f.	Increased SSME Thrust - ascent + abort	630 lb/percent	+13 percent
g.	Increased SSME Thrust - abort only	450* lb/percent	+18 percent
h.	Increased SSME Vacuum I_{sp}	1050 lb/sec	+8 sec
i.	Increased SSME Sea Level I_{sp}	50 lb/sec	NA
j.	Increased ET Propellant	1000 lb/percent	+8 percent***
k.	Reduced Drag	160 lb/percent	-50 percent
l.	Thinner TPS for Orbiter	185 lb/percent	-43 percent
m.	Reduced Insulation (SOFI) on ET	62 lb/percent	NA
2.	Major Discrete Changes		
a.	Strap-On Solid Motors (SOSM)	8,000*-10,200 lb	-
b.	Liquid Boost Module (LBM)	13,750-14,000* lb	-
c.	Composite Case for SRBs	8,400*-12,000 lb	-
d.	Composite Structure/TPS for Orbiter	9,000**lb	-
e.	HTPB instead of PBAN for SRBs	4,000*-6,750 lb	-
3.	Minor Discrete Changes		
a.	Optimum-Expansion Nozzles for SRBs	<6,500 lb	-
b.	Composite Control Surfaces for Orbiter	3,000** lb	-
c.	Elimination of He Purge Requirement for SSMEs	1,675** lb	-
d.	Elimination of SRB Recovery System	1,500 lb	-
e.	Removal of 3-g Limit on SSME Thrust	200 lb	-

*NASA Sources.
**RI, 1980.
***Change may not be accomplished by itself without significant changes in other parameters.

was made at the same time, the resultant payload improvement was greater than the sum of the improvements from the individual changes.) In addition, for the continuous changes the amount of the change in the dependent variable to produce an 8000 lb payload increment is tabulated as a measure of that required from that change alone to achieve the level for Mission 4. Following is a discussion of each of the payload-improvement options beyond thrust augmentation.

OMS propellant made redundant by decreasing the requirement for maneuvering velocity increment on orbit can be offloaded to give a pound-for-pound increase in payload. From the specific impulse of 315 sec for the OMS propellant, each ft/sec of ΔV is equivalent to expenditure of about 25 lb. If the orbit insertion, orbit transfer, rendezvous, or deorbit maneuvers can be reduced, the payload can be increased at this rate. Mission 4 is stated (see IDA, 1978) to require 1050 ft/sec of orbital meneuvering. Insertion from MECO (suborbital to dispose of the ET) to circular orbit at 57-nmi altitude requires about 500 ft/sec; transfer from 57-nmi circular to 150-nmi circular requires about 335 ft/sec; transfer to a 140-nmi phasing orbit and return requires about 70 ft/sec; and deorbit from a 150-nmi circular orbit to produce a perigee at 40 nmi for a low-angle reentry requires another 200 ft/sec or so, giving a rough total of 1105 ft/sec, providing a measure of the accuracy of the calculations. Of these ΔVs, only the initial OMS orbit-insertion burn seems to be subject to reduction. The tradeoff would be OMS propellant with a lower I_{sp} to accelerate a lower mass (the Orbiter alone), against O_2/H_2 propellant, using a longer SSME burn toward orbital velocity, with a higher I_{sp} to accelerate a heavier mass (the Orbiter plus ET). If the SSMEs were used instead of OMS, the tradeoff indicates only about 2 lb of payload would be gained for each ft/sec substitution, and there would be an increased uncertainty in ET impact point as the ET is carried closer to orbital velocity. Determination of a reduction in OMS requirement would therefore seem to require more sophisticated considerations than the above.

Shorter SRB burn times would be achieved with a faster-burning-rate propellant composition. The burning rate of hydroxy-terminated polybutadiene (HTPB) propellant, for example, is said (Hercules, 1980) to be tailorable over a factor of two by adjusting ammonium perchlorate particle size. A faster burning rate would lead to a higher thrust from a higher chamber pressure and/or a larger nozzle. Each second of reduction in SRB burn time below 120 sec is calculated, in the IDA analysis, to lead to a Mission 4 payload increment of 560 lb, ignoring any weight changes in the case, insulation, or nozzle required by the faster burning rate. Additionally, each second of reduction is calculated to lead to an increase in max q by about 9 lb/ft^2. A reduction in SRB burn time of 14 sec from 120 would provide a gross increase in payload of 8000 lb and an increase in max q of about 130 lb/ft^2 from the 654 lb/ft^2 baseline. Such a burn-time modification would probably require development and test firings for requalification.

Payload sensitivities to other SRB parameters are listed in Table II-5.

Each percent increase in SSME thrust rating beyond 109 percent for a nominal-ascent trajectory is calculated, in the IDA analysis, to produce an increment in Mission 4 payload by about 630 lb, ignoring any engine weight increase, structural penalties, or any change in specific impulse. The accompanying increase in max q is about 4 lb/ft^2 per percent. The payload increase from a one second increase in SSME vacuum I_{sp} is calculated to be 1050 lb; from a one second increase in sea level I_{sp}, 50 lb. The proposed uprating to 115 percent thrust (RI, 1980) involves a 1.5-sec increment in vacuum I_{sp} and a 1.3-sec increment in sea level I_{sp}. The overall payload increment for the 115 percent thrust level (over the 109 percent level) is therefore 6500 lb from the partial derivatives or 6800 lb from a trajectory calculation involving all the changes at once, including the 1675-lb credit for elimination of helium purge and 600 lb for engine weight growth. The RI payload increment is 8100 lb. NASA gives (NASA, 1980e) a gain of 7500 lb without specifying whether the helium credit is taken or not. An increase in SSME thrust beyond 109 percent would almost certainly entail some component modifications with an increase in engine weight, or possibly a reduction in engine life. NASA plans to explore the feasibility of uprating the SSME to 115 percent thrust. However, tests for this uprating are not expected to begin until the completion in 1983 of the engine test program directed toward multiple reuse and design life requirements. Further uprating of the SSME beyond the 115 percent thrust level is not considered likely by Rocketdyne or NASA short of a major redesign and development program for the engine.

The current ET propellant loading is calculated in this analysis to be very nearly optimum for 109 percent thrust (Fig. II-10), but for increased SSME thrust, increased ET propellant shows a payoff. Results of RI calculations are also given in the figure showing total Mission 4 payload increments (from both thrust and ET-propellant increases) of about 15,000 lb for an increase in ET propellant of 250,000 lb (16 percent) for 115 percent thrust, and about 30,000 lb for an increase in ET propellant of 280,000 lb (18 percent) for 130 percent thrust. IDA calculations give 15 to 20 percent less payload improvement than does RI. No explanation of this difference has been provided at this writing.

An arbitrary reduction in Shuttle drag of 50 percent was made in the IDA calculations; the Mission 4 payload increase was about 8000 lb (Table II-5) and max q was increased 44 lb/ft^2. The intent here was to determine a measure of the potential reward from some scheme, e.g., aerodynamic fairings between components, that might reduce the overall vehicle drag during the boost phase. While a 50 percent reduction in Shuttle drag may be unrealizable, a reduction of only 5 percent would provide a payload increase of about 800 pounds.

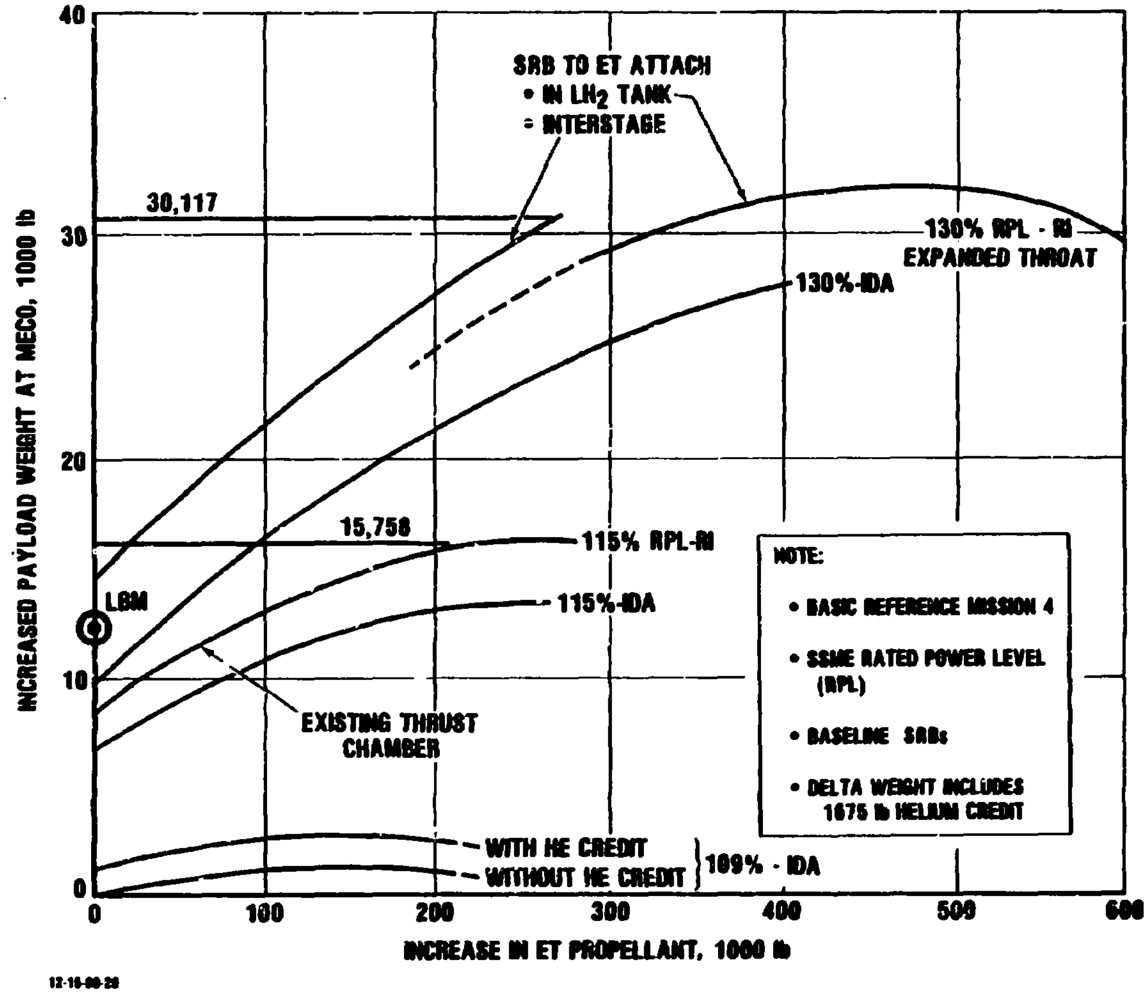


FIGURE II-10. Mission 4 Payload Increase with Increased SSME Thrust and Increased ET Propellant

The reusable external insulation thermal protection system (TPS) for the Orbiter weighs about 18,500 lb. If flight measurements indicate that the heating rates are less than those allowed for, some reduction in TPS weight, with a pound-for-pound increase in payload weight, would be possible. The 8000-lb required payload increment could be met with a 43 percent reduction in TPS weight. If experience does not allow a reduction of this size, a lesser reduction could be coupled with other small improvements elsewhere to make up the desired 8000-lb gain.

Likewise, a reduction in the 6200-lb SOFI for the ET may become possible based on flight experience. A reduction here alone could obviously not meet the required 8000-lb increment but would supplement other modifications that would also fall short by themselves. On the other hand, if flight experience should dictate an increase in thermal protection for either the Orbiter or the ET, payload would suffer a pound-for-pound reduction.

In early 1980, Hercules proposed (Hercules, 1980) an upgrading of the SRB composed primarily of a substitution of a fiberglass case (Fig. II-7) for the steel case. Four glass filament-wound case segments would replace eleven steel case segments in their proposal for a weight savings of 62,900 lb per SRB or a reduction of 34.3 percent in inert weight. The contribution to the weight savings due to reduction in number of segments, and number of joints, was not broken out. The fiberglass case is to fit in the same envelope as the steel case to avoid any requirement for dimensional change in handling facilities, and it is to have the same attach points to preclude any impact on the Shuttle stack. The 34.3 percent reduction in SRB inert weight is estimated by Hercules to produce a Mission 4 payload increment of 10,650 lb. IDA calculations for the same inert weight reduction give a 11,800 lb payload increment. Aerospace Corporation (Aerospace, 1980a) estimates a 50,000-lb case weight (27.3 percent) reduction and a 9,000-lb payload improvement. NASA (NASA, 1980e) indicates an 8,000-lb payload improvement.

Hercules estimated (Hercules, 1980) that qualification of modified SRMs (incorporating any or all of the possible upgrading options, including shorter burn time) would require three test firings involving a non-recurring cost of $60 million.

For operational flights, Hercules proposed that the fiberglass-case SRBs be recovered as usual in order to allow the expensive ancillary equipment aboard to be recovered for reuse, but that the fiberglass case would not necessarily be reused. Reuse was not felt to be impractical, but initial Hercules analysis was not conducted in enough depth to include refurbishment considerations. The ancillary equipment, e.g., nozzle, separation thrusters, recovery gear, were envisioned to be the same as for the steel case. The discarding of the fiberglass case after use was estimated by Hercules (op.cit.) to cost about $1.5 million more than the cost for the steel case over 12 reuses with a reflight cost of 13 percent of first article cost.

The principal questions regarding the ability of fiberglass (or any other composite) to substitute for steel concern its structural strength and its stiffness. The structural requirements are most critical in the joining of segments and in the function of the SRB cases as strongbacks for the Shuttle stack in transmitting weight and thrust loads. A critique by Aerospace (Aerospace, 1980a) revealed the following reservations regarding the Hercules proposal:

a. The system loads analysis did not appear to be comprehensive enough to assess the impact of the composite case distortion, linear and angular, caused by the internal pressure.
b. Loads on the upper hemispherical dome may have been underestimated by upwards of a factor of three.
c. Attachment details (i.e., clevis joints and aft skirt) were sketchy and may not have been thought

through adequately. Steel reinforcements would probably be required at critical points. The fact that the system loads will have to be supported through the SRBs for long periods (e.g., a month) on the launch pad did not appear to have been considered.

d. Dynamic loads were apparently not evaluated and could result in considerable weight increases over the proposed baseline.

e. Thrust vector control authority may be reduced because of banana-like bending of the booster case under internal pressure.

f. Current production tooling and handling fixtures are geared to handle steel cases that are stiffer than fiberglass. Modifications may be very expensive, as much as $100M.

g. The development program should probably involve twice as many firings as proposed, as many as six.

None of the foregoing shortcomings of the Hercules proposal was viewed as insurmountable; successful development should be possible but would require careful design and would involve increased risk in comparison with the LBM and its "off-the-shelf" components.

Rockwell has proposed (RI, 1980) replacing the current Orbiter structure and TPS with composite material; their estimate of the potential Orbiter weight reduction, and hence payload gain, is 9000 lb.

Another facet of the Hercules SRB-upgrading proposal (Hercules, 1980) was a recommendation for substitution of HTPB propellant for polybutadiene acrylonitrile (PBAN) with a 3.2-percent increase in propellant density (and hence weight) due to a lower-viscosity binder leading to higher (90 percent) solids loading, with a consequent 2.8-sec increase in specific impulse. Hercules calculations of the consequent payload gain gave 6680 lb; the IDA result was 6750 lb (if burn time is held fixed). A NASA estimate (NASA, 1980e) was 4000 lb.

IDA trajectory calculations give values for the partial derivatives (Table II-5) for SRB changes as 340 lb of payload for a one-percent change in SRB inerts, 2230 lb of payload for a one-percent change in SRB I_{sp} (keeping burn time fixed) and 1380 lb of payload for a one-percent change in SRB propellant weight (again for fixed burn time). The results of individual calculations for different SRB parameters, for the SOSM, and for the LBM are plotted in Fig. II-11 in terms of the maximum dynamic pressure as a function of Mission 4 payload improvement. In general, max q increases directly with payload, and for a burn time of 120 sec max q versus payload appears to be a straight line with a slope of about 4 lb/ft^2 per thousand pounds of payload.

Reviews by MSFC (MSFC, 1980b) and Aerospace (Aerospace, 1980a) expressed the following observations about the substitution of HTPB for PBAN:

a. For manned space flight, HTPB may have an inadequate data base in experience and properties definition.
b. The HTPB binder has better mechanical properties than PBAN and probably would be mandatory in the more flexible (than steel) fiberglass case.
c. The high (90 percent) solids loading probably would cause extensive nozzle erosion, thus requiring a heavier nozzle. The danger of excessive slag formation is increased with little gain in performance over an 88-89 percent mixture.
d. The hotter products of combustion will require a reassessment of the insulation requirements.

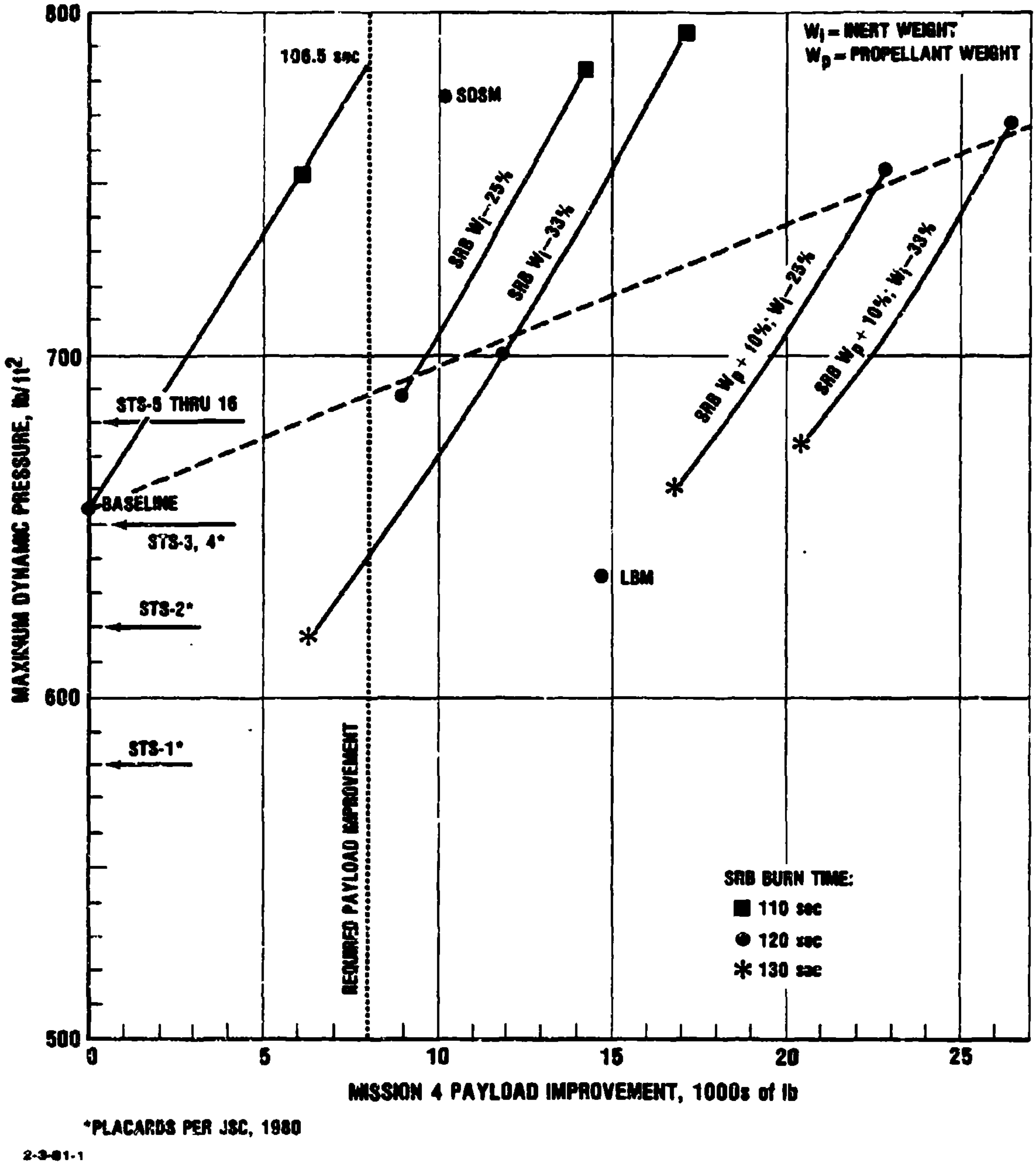


FIGURE II-11. Mission 4 Payload Increase and Maximum Dynamic Pressure for Thrust-Augmentation and SRB-Upgrading Options (Baseline: OV-103; ET-7; SSME 109/109%; and HPM) IDA Trajectory Calculations

Increased insulation will reduce the volume available for propellant, with consequent performance losses.

e. The addition of HMX was suggested as a way to lower the combustion temperature to reduce the insulation requirement.

Included in the Hercules proposal was the suggestion for optimizing the expansion ratio of the SRB nozzle, increasing the ratio from 7.16:1 to 10:1. Their estimate of the consequences gave an 8-sec I_{sp} increase for a 1000-lb weight increase for each nozzle. Their calculated payload increment was 3600 lb; the IDA result was 6470 lb (keeping burn time fixed). A 10:1 nozzle was viewed by Aerospace (Aerospace, 1980a) as requiring major modifications to launch mounts at both KSC and VAFB. Also ground handling facilities (e.g., autoclaves) would be significantly impacted.

Replacement of Orbiter control surfaces with composite material has been proposed by Rockwell (RI, 1980). Their estimate of the Orbiter weight reduction, and hence payload gain, is 3000 lb.

Removal of the equipment required to effect SRB recovery would give a payload gain of about 1500 lb.

At about 400 seconds of the SSME burn, the longitudinal acceleration level reaches 3 g's. At this point, the SSMEs begin to be throttled down to prevent the acceleration from exceeding this value. If the throttling did not take place, the g's would continue to rise to about 5 at MECO. The payload gain if this throttling were not done would be about 200 lb.

E. CONCLUDING REMARKS

From the standpoint of schedule, none of the Shuttle uprating options, even the most difficult example, the composite SRB case development, appears to the organizations interrogated to require for implementation more than the five or so years until the first Mission 4 flight is to occur. From the standpoint of cost, insufficient data exist today to provide a ranking of the options; considerable further study effort by NASA will be required to define the costs adequately. Ongoing NASA studies (NASA, 1980c) are examining five areas: (1) the liquid boost module, (2) uprating the SSME to 115 percent, (3) a filament wound SRB case, (4) HTPB propellant for the SRB, and (5) hybrid rocket motors in place of the SRBs. These studies are expected to define comparative development risks, determine major systems impacts, and provide estimates of DDT&E and operational costs by mid-FY 1981.

There are those in NASA and elsewhere who anticipate that the early flights of the Shuttle will provide data to indicate the more promising avenues for improving the Shuttle performance, e.g., reducing the weight of the Orbiter TPS, reducing the weight of the ET SOFI, and operating the SSME safely at thrust levels beyond 109 percent. A combination of such relaxations from initial conservatism, in addition to the planned improvements in reduction of the structural weight of Orbiters 103 and 104, in the lightweight ET, and in 109 percent thrust SSMEs, might be sufficient to achieve the desired performance for Mission 4 without resorting to a concerted development program for thrust augmentation or a composite-case SRB. While such optimism cannot currently be substantiated, it (and the variety of available payload-improvement options) does indicate that the issue of thrust augmentation should be left open to further debate until a decision date in mid-FY 1981 is reached.

If the above relaxed flight tolerances do not become available, operational experience and loads information for the SRBs may allow the current steel-case SRBs to be redesigned, and with a higher-energy propellant and a shorter burn time, to achieve gains comparable to those derivable from the composite design with little, if any, impact on manufacturing, ground handling, and launch facilities.

A number of feasible Shuttle payload improvement options exist, so that the required 32,000-lb Mission 4 payload should be achievable in the available time, provided NASA can commit funding in FY 1982 and can apply suitable resources. The sum of all the possible options is great enough that in the long term (after 1990, say) a properly conducted sustaining engineering effort at a presently undefined rate of expenditure could even increase the Shuttle payload in the 98-degree, 150-nmi orbit to double the present requirement, to the current Orbiter structural limit of 65,000 lb into any orbit.

III. SHUTTLE OPERATIONAL CONSIDERATIONS

A. GROUND HANDLING

A review of progress in plans for the ground handling of DoD payloads revealed that the most significant development in the past year was the modification of the original Air Force "factory-to-pad" concept at KSC, which called for a minimal final checkout of the payload at the pad after delivery from the supplier. Instead, as described and endorsed in IDA 1979, current plans call for a modification of the Solid Motor Assembly Building (SMAB) at KSC to allow for off-line processing of payloads, including assembly and checkout, prior to installation at the launch pad. This procedure is similar to that already planned for VAFB and should result in a more uniform payload handling routine, with significant advantages in operations and costs.

At this time a more immediate concern in regard to payload handling is the uncertainty in scheduling payload operations associated with the Shuttle launch-rate capability. Many factors influence Shuttle launch rate--Shuttle turnaround time, availability of processing facilities such as the number of cells in the Vehicle Assembly Building (VAB), the number of Orbiters and the number of launch pads, and unscheduled interruptions, such as an accident with an Orbiter. Numerous studies have been conducted relating to the launch-rate issue. The most comprehensive study available at this time is one conducted several years ago (Joint, 1976). However, some details of a more recent study relating to this issue were provided IDA by NASA (KSC, 1980a). The results are noteworthy even though preliminary, for while the specific numbers relating to turnaround time and flight rates will undoubtedly change as operational modifications are introduced and experience acquired, the relative importance of the pivotal factors involved are not apt to change significantly.

A projection of KSC turnaround time evolution is shown in Fig. III-1. The processing times given are estimates and are presented to give a measure of the effort involved in preparing the Shuttle for flight. The main point of interest in the figure relates to the anticipated reduction in turnaround time projected for the subsequent flights as learning is acquired and hardware problems presumably diminish. It will be noted, however, that the turnaround times shown are much longer than the 3.5-week operational turnaround assessment or the 2-week (160-hour) operational turnaround allocation specified in NASA's Level I Space Shuttle Program Requirements Document.

The turnaround time problem continues to receive major attention at KSC. A special team called STAG (Shuttle Turnaround Assessment Group) was formed in 1979 to monitor and review the entire process. A preliminary finding of STAG was that for Shuttle flights employing upper stages (i.e., IUS) the turnaround time was 233 hours; for Spacelab flights, the time was extended to 275 hours. The weighted average ground-operations flow from this preliminary study was 246.5 hours or about 14 days. Using these ground flow times, and the STS flight traffic baseline detailed in Table III-1, the study focused on a calculation of the estimated maximum Shuttle launch rates. The results of this portion of the study are given in Table III-2. The KSC analysis projected an estimated maximum flight rate of 13 flights per year per Orbiter, indicating that a total of 39 flights per year could be flown with a fleet of 3 Orbiters, in good agreement with the maximum flight rate of 40 flights per year with a fleet of 3 Orbiters set ten years ago and equal to the estimated maximum required rate of 40 shown in Table III-1. However, when a detailed Ground Processing Simulation (GPS)

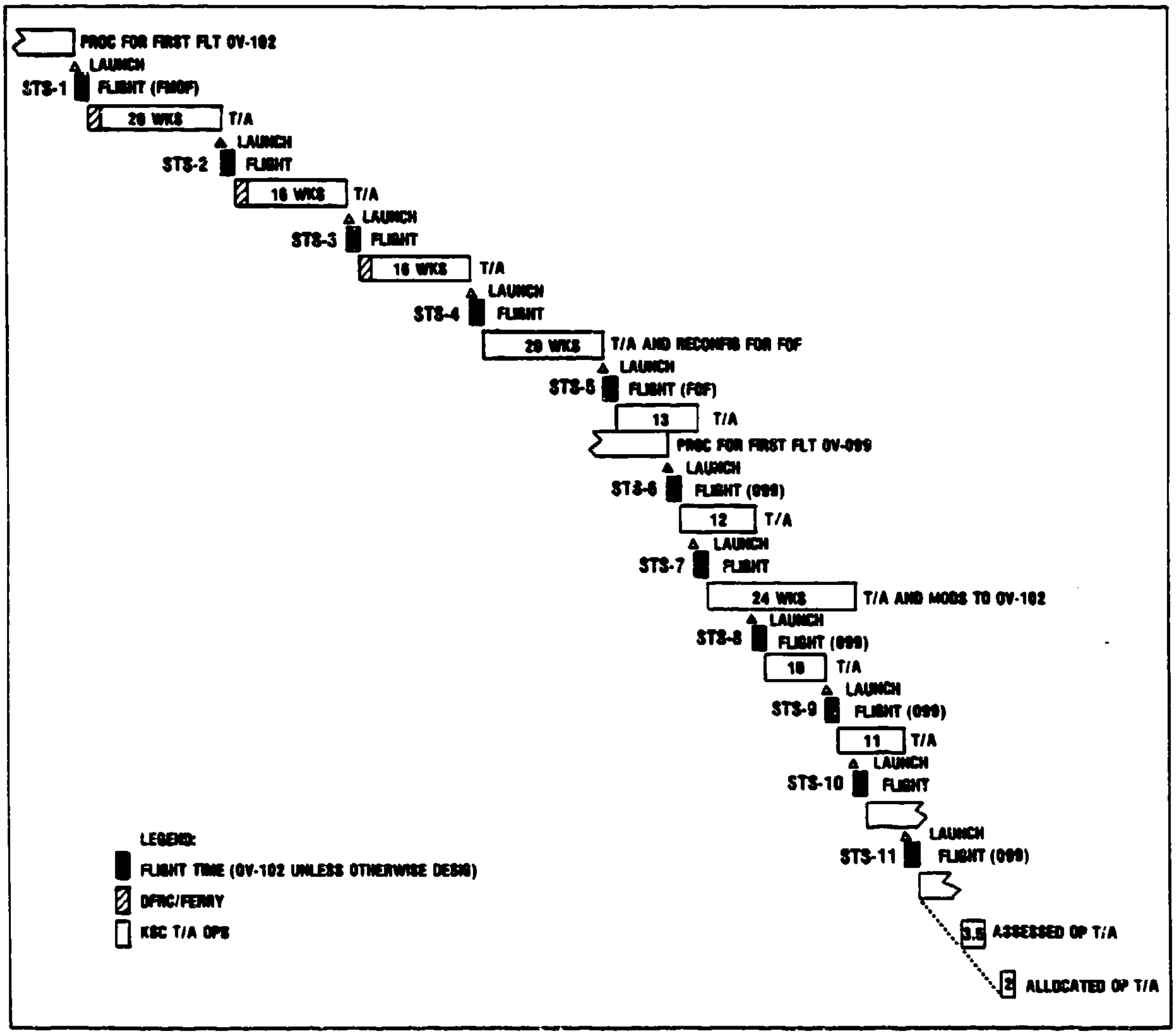


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FIGURE III-1. Turnaround Evolution Assessment (KSC Sources)

TABLE III-1. STS FLIGHT TRAFFIC BASELINE (REF: KSC, 1980b)

NOTE: ONLY OPERATIONAL FLIGHTS SHOWN

ASSUMES TRANSFER OF OV 102 TO VAFB IN OCT. 1983		
ORBITER DELIVERIES		FOF: 9/82
OV-102 3/79 OV-099 6/82	OV-103 9/83 OV-104 12/84	

BY STS ELEMENT

		FY 1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
KSC	SPACELAB	-	1	5	5	8	9	9	10	10	10	10	10	9	96
	UPPER STAGES	1	6	6	10	12	15	17	22	22	22	22	22	20	199
	FREE-FLYERS	-	-	1	1	1	2	2	2	2	2	2	2	1	18
	LARGE STRUCTURES	-	-	-	-	1	2	3	4	4	4	4	4	3	29
	REFLIGHTS	-	-	-	2	2	2	2	2	2	2	2	2	2	20
	TOTAL KSC	1	7	14	18	24	30	33	40	40	40	40	40	35	362
VAFB	SPACELAB	-	-	-	-	1	-	1	2	1	2	2	3	2	14
	UPPER STAGES														
	FREE-FLYERS	-	-	-	4	5	9	13	12	13	12	12	11	12	103
	REFLIGHTS	-	-	-	-	-	1	1	1	1	1	1	1	1	8
	TOTAL VAFB	-	-	-	4	6	10	15	15	15	15	15	15	15	125
FLIGHT TOTAL		1	7	14	22	30	40	48	55	55	55	55	55	50	487

TRAFFIC PROJECTION - FOR PLANNING PURPOSES ONLY

TABLE III-2. ESTIMATED MAXIMUM RATES (COURTESY KSC)

ASSUMED: PROCESSING TIMES FROM KSC, 1980a.
5-DAY/2-SHIFT WORK DAY EXCEPT PAD OPS WHICH ARE 5 DAY/3 SHIFTS.
AVERAGE 4 DAY MISSION DURATION (AVERAGE OF 1ST 35 FLIGHTS).

TOTAL ORBITER FLOW TIME DERIVED FROM WEIGHTED AVERAGE OF 32.6% SPACELAB AND 64.4% UPPER STAGES (BASED ON MIX FOR FY-82 THRU FY-86).

WEIGHTED AVERAGE GROUND FLOW TIME - 246.5 HRS OR 14+ DAYS.

	ESTIMATED MAX FLIGHT RATE PER YEAR
ORBITER	13
FACILITIES	
ORBITER PROCESSING FACILITY (OPF) TEST BAY	27
VEHICLE ASSEMBLY BUILDING (VAB) INTEGRATION CELL & SRB PSF COMB. (HB 3 & 4 OR HB 1 & 2)	19
MOBILE LAUNCH PLATFORM (MLP)	16
PAD	42

analysis is made, considering realistic flight schedules and conflicts in occupancy of available facilities, limiting flight rates as shown in Fig. III-3 are obtained, indicating a maximum capability of 30 flights per year in 1985. (The most recent STS Flight Traffic Baseline shown in Table III-1 shows a maximum flight rate of 40 flights per year projected for 1989 for KSC.) In addition, in Table III-2 are shown the influences of various facility assumptions on the limiting flight rates. Three critical elements identified are the Orbiter Processing Facility (OPF) cell, the set of Vehicle Assembly Building (VAB) cells, and the Orbiter; reduction by one below the approved number of any of which would reduce the flight capacity from 30 to near 20 flights per year. Incrementing any of these elements does not achieve the desired 40 flights per year, however, so attention must be focused on ways to reduce the time involved in ground processing procedures, such as equipment or techniques to facilitate handling of the Orbiter, authorization of overtime, or reordering flight schedules to reduce conflicts. These are all factors being considered and evaluated in the current schedule review and in studies being conducted by NASA and the USAF.

B. LOGISTICS

Plans for the establishment of a logistic supply chain for support of the Shuttle in its operational phase are in preparation. A joint AF-NASA planning effort is underway to establish training requirements for operational personnel and to provide a mechanism for furnishing the necessary hardware and spares at both KSC and VAFB for STS operations. For example, a Shuttle Inventory Management Supply System (SIMS) has been established with the inventory data stored in a centralized computer. Remote terminals at various locations (VAFB, MSFC, etc.) provide direct access to the Inventory. All elements of the STS system are covered, including Ground Support Equipment and components from

TABLE III-3. FACILITY SENSITIVITY ANALYSIS DATA (COURTESY KSC)

FY	81	82	83	84	85
ESTIMATED MAX. RATES (LIMITING COMPONENT)	13(ORB)	26(ORB)	26(ORB)	38(VAB)	38(VAB)
487 MODIFIED TRAFFIC MODEL	7	16	18	25	30
BASELINE GPS RUN	7	15	18	27	29
BASELINE WITH 2-DAY PAD CONTINGENCY REMOVED	7	16	19	28	30
NO CONTINGENCY-2nd OPF CELL REMOVED IN FY84				17	20
NO CONTINGENCY-2nd SET OF VAB CELLS REMOVED IN FY84				18	19
NO CONTINGENCY-3rd MLP REMOVED IN FY84				27	27
NO CONTINGENCY-2nd PAD REMOVED IN FY84				27	30
NO CONTINGENCY-3rd ORBITER REMOVED IN FY84				23	23
NO CONTINGENCY - ADDED 3rd OPF IN FY84				31	31
NO CONTINGENCY - ADDED 3rd SET OF VAB CELLS IN FY84				28	31
NO CONTINGENCY - ADDED 4th ORBITER IN FY84				30	34

ESA (European Space Agency). KSC is the manager of this system. Planning meetings are held regularly at all major contractors supplying elements of the STS system, including meetings in Europe with ESA concerning the Spacelab and in Canada with SPAR concerning the Remote Manipulator System.

An important milestone in joint NASA-AF logistic planning occurred in May 1980. A Space Shuttle Logistics Support Conference was held at VAFB. A number of planning issues were reviewed and action items assigned to specific organizations for clarification, amplification, or implementation. Two major items relating to logistics requirements were identified as:

1. A plan and schedule for the development and implementation of Information Management Systems.
2. A plan and schedule to implement operational era item management for each logistics function.

Item 1 pertains to information and documentation necessary for maintaining the Shuttle fleet in a state of readiness. It covers such publications as SIMS (Shuttle Inventory Management Supply System), Action Directives, and Operational Maintenance Documents (OMD). This is a basic NASA planning responsibility inasmuch as NASA is the STS developer and is responsible for Configuration Management. Item 2 is critical to efficient and timely scheduling and will affect activity at both USAF and NASA facilities.

All major aspects pertaining to logistics planning appear to be addressed. Of some concern, however, is the budgetary situation for logistics items. R&D funding for the Shuttle takes precedence in NASA's budget and the funds allocated to STS operations are not as great as some logistics planners would like at this stage. However, it is too early to assess the impact this may have on operations because of the stretch-out in the Shuttle development schedule.

IV. SHUTTLE SURVIVABILITY

This chapter has been published under separate cover. The document carries the same IDA identification number, P-1531, and is sub-titled as above. The material is published separately because of its classified nature, thus allowing wider dissemination and less restricted usage of this unclassified volume.

V. DOD SPACE EXPERIMENTS AND USE OF MAN

In 1978 the Space Test Program (STP) was selected (AF/RDSL, 1978) to serve as a pathfinder to explore ways to use the Space Shuttle as a manned laboratory in space for DoD space experiments. The primary objective of STP is to respond rapidly to experimenters' needs in the Shuttle era factoring in man's capabilities as a payload specialist to facilitate the process of planning and carrying out an experiment. Response times of less than two years from inception of an experiment to flight have been established as a goal. It is anticipated that, by exploiting man's participation and making efficient use of available space on DoD and NASA Shuttle flights, more experiments could be flown at lower cost than has been possible with expendable launch vehicles (ELVs) and specialized spacecraft. Space flights of this kind are termed Sortie Missions. On a sortie mission the experiment equipment remains in the Shuttle cargo bay and is operated either by automatic control or by an astronaut (or payload specialist) during the time in orbit.

During the past two years considerable effort has been expended by the DoD to define the STP program, determine the nature and scope of Shuttle cargo bay hardware and ancillary equipment needed to support the program, define and specify the kind of training and simulation equipment needed for the crew, and how the experiments can be efficiently manifested and scheduled for Shuttle flights. A discussion of these issues is contained in IDA, 1979. Technical requirements are detailed in RFP, 1980. Inasmuch as the STP program is currently in the process of definition and contractor selection, only a brief discussion of developments underway is included in this report.

At the present the STP program is active in four areas:

1. Experiment Definition and Integration
2. Sortie Support System Acquisition
3. Crew Training
4. Flight Scheduling

1. The definition of the STP experiments is the responsibility of particular program offices within DoD. In this area the STP program office of the Space Division is involved in an advisory and supporting role to assure that maximum use of the unique features of the Shuttle are considered in the plans. However, the STP office plays a major role in experiment integration, flight planning and ground operations. Experiment integration and the costs associated with this activity continue under study by Air Force elements in an effort to understand the nature of the activity and, hopefully, discover ways to reduce manpower requirements and associated costs. Much insight was provided by the representative integration cost exercise report in USAF, 1979. In this study of a typical payload integration task the effort for a second flight was estimated to be only about 46 percent of the effort expended on the first flight (Table V-1). An important factor affecting the comparison is the longer integration schedule required for the first flight--2.5 years as against 1.5 years. The effort required in particular task areas will, of course, vary with the specific experiments or groups of experiments making up the cargo manifest. It can be anticipated that as greater understanding and experience is acquired in actual sortie mission operations, significant reductions in the required manpower can be achieved.

2. The Sortie Support System (SSS) acquisition process is currently underway (RFP, 1980). An SSS contractor was to be selected in Calendar Year 1980. His task will be

TABLE V-1. TYPICAL PAYLOAD INTEGRATION TASKS AND EFFORT
(Data from USAF, 1979)

INTEGRATION TASKS	EFFORT IN MAN-MONTHS FIRST FLIGHT 2.5 YR. SCH.	SECOND FLIGHT 1.5 YR. SCH.
Training Support	19	6
Ground Communication	5	3
Interface Test & Evaluation	19	8
System Project Management	249	71
System Engineering	(20)	(5)
Project Management & Meetings	(74)	(29)
Safety	(17)	(7)
Interface Analysis	(138)	(30)
Data and Report	10	5
Site Activation Support	9	5
Operations	155	115
Ground Operations	(28)	(21)
Flight Operations	(101)	(82)
Flight Readiness Review	(17)	(9)
Contingency Control	(9)	(3)
TOTALS	466	213

to furnish experimenters with necessary flight hardware, support equipment, training equipment unique to STP, and experiment integration, checkout, launch support, orbital support, and payload-return services.

3. The principal issues regarding crew training concern the use of man, the adequacy and timeliness of the training and the degree of sophistication required in the program simulation. While debate concerning the effectiveness of man in the experiment loop continues to flourish in the user community, plans, nevertheless, for the selection, training, and utilization of onboard payload specialists are proceeding in the Air Force. This activity draws heavily on NASA's experience with the training of payload crews for Spacelab. The basis for much of the planning is a study (Aerospace, 1979) prepared for the Space Division. The study draws heavily on NASA's Skylab experience and highlights the performance and effectiveness of the Skylab crews in operations, inspection and evaluation, data analyses, observation, and maintenance and repair. An example cited is the Skylab crew participation in on-orbit analysis of images of the sun from the Apollo Telescope Mount (ATM), originally programmed to be completely automated. It transpired that the on-orbit images could be analyzed more efficiently by the crew in real time rather than transmitting the images to ground. Other examples of productive crew utilization are given in the reference.

4. Flight scheduling continues to present planning problems because of uncertainties in the Shuttle operational date and growing concerns regarding the crowded Shuttle payload inventory. At the time of writing (1980) it appears unlikely that any STP experiments will be flown before Fiscal Year 1984.

The concerns about saturating the Shuttle launch capacity were expressed in a NASA briefing (NASA, 1980a); a convenient summary appeared in AV.WK., 1980. The saturation is attributed to the burgeoning growth of the communications satellite market (U.S. and International), the size of the Shuttle fleet (4), and the longer-than-planned Shuttle turnaround time, as discussed in Chapter III of this report. A fleet-size study is currently underway at NASA to assess the effects of increased traffic on orbiter availability and turnaround time. The study will include an examination of orbital duration requirements for Spacelab experiments. It appears it may be feasible to shorten the duration of certain Spacelab flights by sharing time with other users and by staggering flights, thus providing additional flight opportunities for other programs.

VI. ADVANCED SPACE TECHNOLOGY

During the past decade the major emphasis in space technology has been in the development of the new Space Transportation System (STS). The principal element of the STS is the Space Shuttle. A description of the Space Shuttle and ancillary elements of the STS is given in Refs. IDA, 1977 and NASA, 1979a. The presence of the Shuttle will allow (or even mandate) improvements in military space systems depending on new technologies that can be developed in parallel with the early Shuttle learning period. On the other hand, there are many who are less than enthusiastic about the military potential of the Shuttle and its involvement of man. They argue that an unmanned launch system, perhaps with some reuse capability of major components, will continue to afford the best opportunity for maintaining autonomous military operations with minimal security issues to resolve and no survivability compromises due to the vulnerabilities of man. Nevertheless, the Shuttle is expected to become operational in 1982. It seems timely therefore, to try to identify any trends in military planning and operations, and the associated technology needs, that the availability of the Shuttle could stimulate.

In attempting to delimit the directions in technology that may be required to support or make feasible advanced military missions in space, it is helpful to examine the spectrum of the U.S. military involvement in space and how it might be affected by new technological thrusts complementing the introduction of the Space Shuttle. Table VI-1 lists the four generic military space mission categories. For each category characteristics are noted regarding principal mission functions, the near-term

TABLE VI-1. TAXONOMY OF MILITARY SPACE MISSIONS

CATEGORY	FUNCTIONS	NEAR TERM IMPLEMENTATION	FAR TERM TRENDS	TECHNOLOGY THRUSTS
Observation (Surveillance)	Detection Monitoring	Unmanned Satellites	Lifetime Extension Manned Tending	Man-In-Space Tactical and Servicing Operations Large Structures Orbital Assembly Sensors, Computers Tethered Satellites
Information (Communication & Navigation)	Global Coverage Precise Vectoring	Multiple Satellites Variety of Orbits	Lifetime Extension Common Platforms Higher Data Rate Higher Power	Man-In-Space Servicing Techniques and Methods Teleoperators Large Structures Orbital Assembly
Space Logistics	Delivery Resupply Storage	Current ELVs and Orbit to Orbit Stages Space Shuttle	Manned Orbit-to-Orbit Stages Quick-Turnaround Shuttle Single-Stage-to-Orbit Shuttle On-Orbit Operational Platforms and Depots	Low-Maintenance Reusable Thermal Protection Systems Simplified Turnaround Procedures Dual-Fuel Dual-Expander Propulsion Development Light-Weight Structures Zero-G Propellant Transfer Spacelab Free Flyers
Space Defense	Protection of Spacecraft Mission Neutralization of Threats	Passive Surviv-ability Measures (Hardening, concealment, proliferation) Attack Notification ECM Low-Altitude ASAT	Space Surveillance, C^3 (Attack Warning and Response Activation) Active Survivability Measures (Maneuvering, Decoying, DSAT, Quick Replacement) All-Altitude ASAT	High Physical Survivability Directed-Energy Weapons ASAT Upgrading (Hardening and Smart Sensors) On-Demand Launch Vehicle Space-Based Sensors Faster C^2

means of implementation, far-term trends, and the broad technology thrusts that are likely to be the key contributors to realization of the far-term trends. In the near term (before 1990) it can be expected that military satellites and their use will be little changed from that of the present, except that the launch vehicle will eventually be the Shuttle. The far-term trend, however, at least in the first two categories, would appear to involve introducing the use of large structures as antennas, and incorporating the active participation of man in tactical as well as on-orbit-servicing operations and the employment of ancillary devices such as a teleoperator maneuvering system. Major developments in the space logistics supply systems can also be envisaged, such as a quick-response earth-to-orbit launch vehicle and a manned orbit-to-orbit transfer vehicle for transporting and servicing satellites and facilities located in geostationary orbits. Future developments in active space defense must be considered conjectural because of uncertainties in international agreements regarding this area; the present near-term passive means of implementation will be continued and possibly extended into the civil area insofar as communications satellites are concerned.

There are many areas of technology that obviously overlap these mission categories and which should benefit in a synergistic way from this sharing situation. In addressing the task of identifying needed technology developments, the Aerospace Corporation (SD, 1980a) suggested the idea of an "Architectural Sieve" that in their view would provide, in essence, a sifting procedure to determine those key technologies that must be available to support a new performance capability, or "opportunity" in Aerospace terminology. Table VI-2 illustrates the idea. Four layers of the imaginative "sieve" are depicted. First, the application and its operational time period are identified. Next, the features of the application are highlighted, followed by statements of its relevance in terms of its potential

TABLE VI-2. SUGGESTION: AN ARCHITECTURAL SIEVE (COURTESY: AEROSPACE CORP)

OPPORTUNITY (operational time period)	FEATURES	RELEVANCE	KEY TECHNOLOGIES
GLOBAL INFO/C^3 NETWORK (early 90's)	• ALL-SOURCE • 10^2-10^3 MBPS DATA TRUNKS • HI/LO DATA RATE TAP-OFF BY USERS ON DEMAND • REDUNDANT SAT-SAT LINKS, AUTO-RECONFIGURATION • SMART TERMINALS	• MODERATE-TO-HIGH CONFLICT LEVELS • FOLLOW-ONS TO DSP/SED DSCS III, GPS III, SCF RTS • 2? CONTROL OF THEATER RPVs • DATA FUSION CENTERS • NASA TDRSS, NEEDS • SAT BUSINESS SYSTEM • REMOTE SENSING SYSTEM DATA DISTRIBUTION	• ON BOARD DATA PROCESSING • SAT-SAT LINKS, e.g., LASER, V-BAND • MIL SPEC VHSIC/RAPID ACCESS MEMORIES • TERMINAL DESIGN/HUMAN INTERFACE
ADVANCED MILITARY SPACE TRANSPORTATION (mid-late 90's)	• MANNED FULLY REUSABLE • DEMAND MISSIONS • FAST RESPONSE (hrs) • LOW COST, SMALL FLEET (~5) • FORCE EXERCISE • BASING FLEXIBILITY • HIGH SURVIVABILITY	• MODERATE-TO-HIGH CONFLICT LEVELS • ALL MISSIONS • NASA SHUTTLE UPGRADE AND FOLLOW-ON REQS • COMMERCIAL SHUTTLE	• CHEM PROPULSION I_{sp}(VAC) → 465 sec • COMPOSITE MATERIALS, ADV STRUCTURES INERT FRACTION → 0.10
ON-ORBIT OPERATIONS (evolving beginning in early 80's)	• CHECKOUT AND DEPLOY • INSPECT, REPAIR, UPGRADE, REFURBISH, ACTIVATE, RETIRE, RETRIEVE • MAKE AND PROCESS • TEST AND EXPERIMENT • CONDUCT SORTIE MISSIONS • RESCUE	• LOW CONFLICT LEVELS • DEVELOPMENT, DESIGN, ACQUISITION OF DOD SPACE SYSTEM • LARGE STRUCTURES IN SPACE • SPACE DEFENSE MONITORING AND DAMAGE ASSESSMENT • COMMERCIALIZATION OF SPACE • SPACE TEST PROGRAM • STANDARDIZATION • SPACE DEBRIS CONTROL	• CREW TRAINING, ENDURANCE AND SURVIVABILITY • MISSION ASSIST, e.g., - TELEOPERATORS - MICRO PROCESSORS - CLIENT DESIGN FOR SERVICING - TUMBLESAT CAPTURE - RETRIEVAL ROCKET PACKS
LARGE SPACE STRUCTURE SYSTEMS (mid-late 90's)	• 10^2-10^3 ft DIA ANTENNAS	• MODERATE-TO-HIGH CONFLICT LEVELS • BATTLEFIELD SENSOR R/0-70', 3 kw • RPV CONTROL-200', 100 kw • TROOPER COMM-250', 100 kw • BATTLEFIELD ILLUM-1000', 2 kw • JAMMER-2000', 300 kw • MULTISTATIC RADAR-1100', 500 w • CIVILIAN LARGE SPACE STRUCTURES	• CONSTRUCTION IN SPACE • ATTITUDE AND FIGURE CONTROL • HIGH POWER SUPPLIES - NUC REACTOR > 20 kw • SURVIVABILITY
HIGH PHYSICAL SURVIVABILITY (continuing)	• BACKUP PAYLOADS - SPARES ON ORBIT - DEMAND LAUNCH • AUTONOMY FROM GROUND STATIONS • KEEP-OUT ZONE MONITORING • DEBRIS CONTROL	• ALL CONFLICT LEVELS • ALL MISSIONS • ON-ORBIT OPERATIONS • ADVANCED MILITARY SPACE TRANSPORTATION • LAUNCHER OPTIONS/SALT	• AUTONOMOUS SPACE NAVIGATION/FAULT TOLERANT SP COMP • EMERGENCY SATELLITE DESIGN • KEY TECHNOLOGIES FOR RELEVANT OPPORTUNITIES INDICATED

significance. Finally, the key technologies are identified and categorized. Five examples are given: a system application (global info/C^3 network), two support functions (space transportation and on-orbit operations), a building block (large space structures), and a system characteristic (survivability).

One example of particular relevance to IDA Shuttle studies is Advanced Military Space Transportation. This application ("opportunity") would influence both military and civil sectors. DoD efforts in this area will be based on investigations by both USAF and NASA and pertain to both Survivable Military Launch Systems and Shuttle follow-ons. The technologies identified call for advances in chemical propulsion and in lightweight structures and materials. (Additional important technology items critical to lower-cost space transportation operations included in Table VI-1 are low maintenance reusable thermal protection systems and simplified turnaround procedures.) On-orbit operations and Large Space Structures are also opportunities with broad relevance to both military and civil programs. It is evident that the applications considered in this chart are not necessarily isolated but are mutually interactive in the technology areas.

Perhaps the most significant point to be made at this time about advanced technologies that might be needed to support future missions in the Shuttle era is that the nature of the missions may only become evident after some operational experience has been accumulated with the Shuttle and its crews. Reference DoD, 1979 cites several illustrations of man's capabilities in space as unexpectedly revealed in NASA's Apollo and Skylab programs. On the Apollo 11 mission, the on-board computer became overloaded to a degree that manual override by an astronaut in the last seconds before lunar touchdown was required to prevent failure of the mission. Principal investigators for the Apollo Telescope Mount on Skylab reported that fully one-half of the experiments planned, all in an automatic mode, would not have been successful had it not been for the resourcefulness and ingenuity of the crew in coping with problems in the system.

These examples focus on the positive contributions that man can bring to the system. On the other hand, experimental conditions can be postulated where the presence or participation of man appears unnecessary or even undesirable. For example, not only can man's continual presence for maintenance of the Space Telescope (ST) not be shown to be necessary, but his natural motions could cause unacceptable disturbances during the long photographic exposures involved in the ST's mission. It is not the purpose of this discussion to attempt to establish hard and fast rules as to when and under what conditions an astronaut or mission specialist can best be utilized but rather to encourage consideration of their use inasmuch as they will be available. It can be observed that just as the use of astronauts to repair a damaged solar panel and erect a mission-saving sunshade on Skylab had not originally been predicted as a practical or feasible use of man in space, so also the details of the potential use of man in space for military purposes will not become evident until some experience in manned military missions in space is gained.

Another aspect of advanced space technology activity is worthy of attention. In the past, frequent R&D undertakings in the centers of this activity in both the Air Force and NASA have not been closely coordinated with the operational elements of these organizations, with the result that little feedback was generated to help guide either group in structuring their plans and objectives. An important step has been taken by the Air Force to help avoid this situation in the future. A planning structure has been devised by the Space Division (SD, 1980b) to provide a two-way exchange of information between USAF (and NASA) R&D centers and the USAF operational organizations that will ultimately benefit from technology advances. The goal is to ensure that an adequate technology base exists to support options for future space systems, as well as to identify and preserve new options that may grow from the technology base. The organization established within the Space Division to achieve this end is shown in Figures VI-1, VI-2 and VI-3. The organization seems well structured and should be effective in accomplishing its goal, providing the key personnel in charge of the principal coordination segments are knowledgeable in their fields, sensitive to new and challenging ideas, and possess the authority to influence the process of selection of systems by the operational commands. A gap in the Technology Planning Method (Fig. VI-3) recognized verbally in discussions at the Space Division but not stated on the chart is a path for feedback from the technology assessment process to help identify new needs of the users that may not previously have been thought possible to ask for (Needs Determination). However, this apparent shortcoming may be mitigated by the activation of the Space Concept Analysis teams proposed by the Space Division (Fig. VI-1).

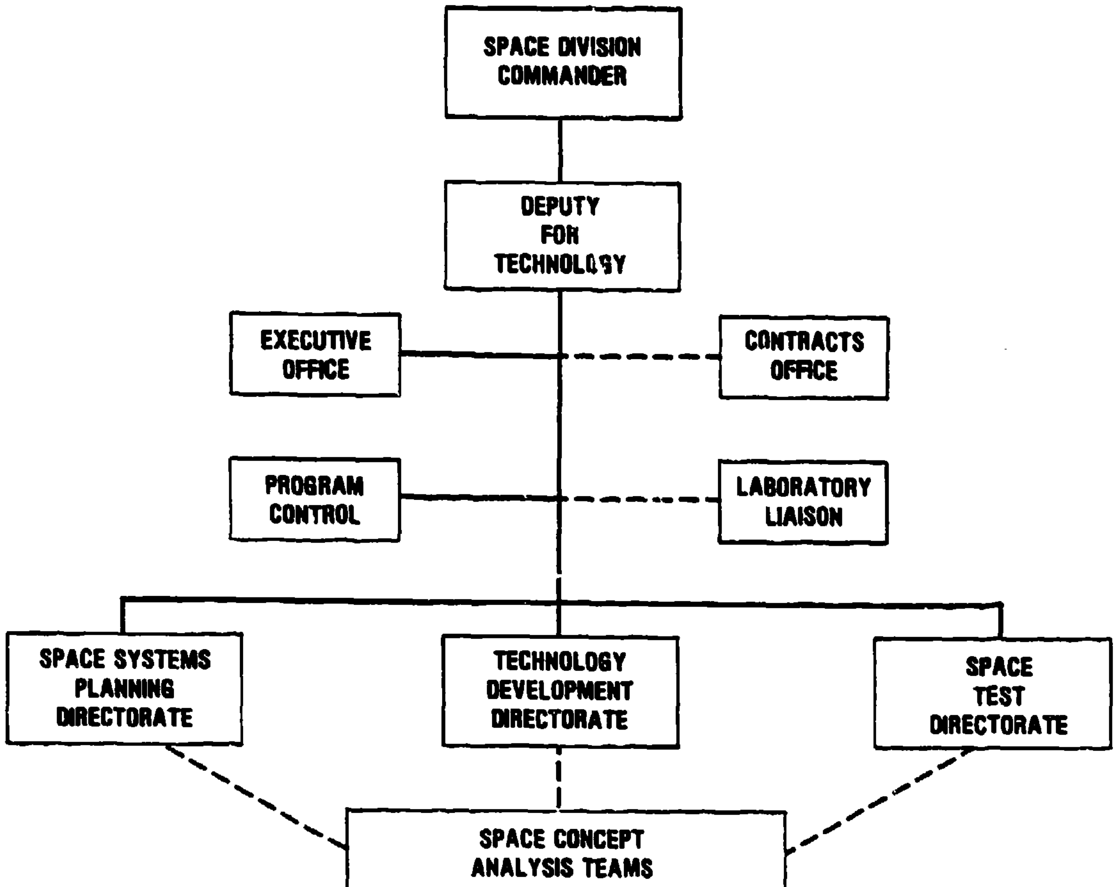

FIGURE VI-1. Space Division Organization for Technology Coordination (Courtesy SD)

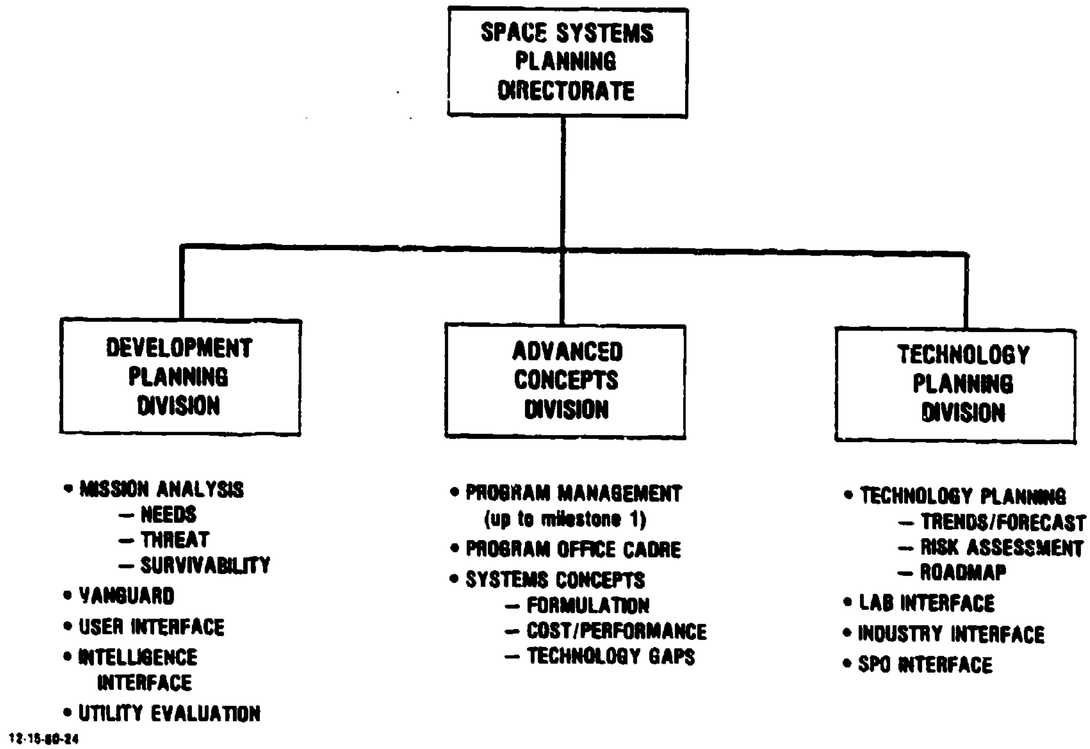

FIGURE VI-2. Space Planning Organization (Courtesy SD)

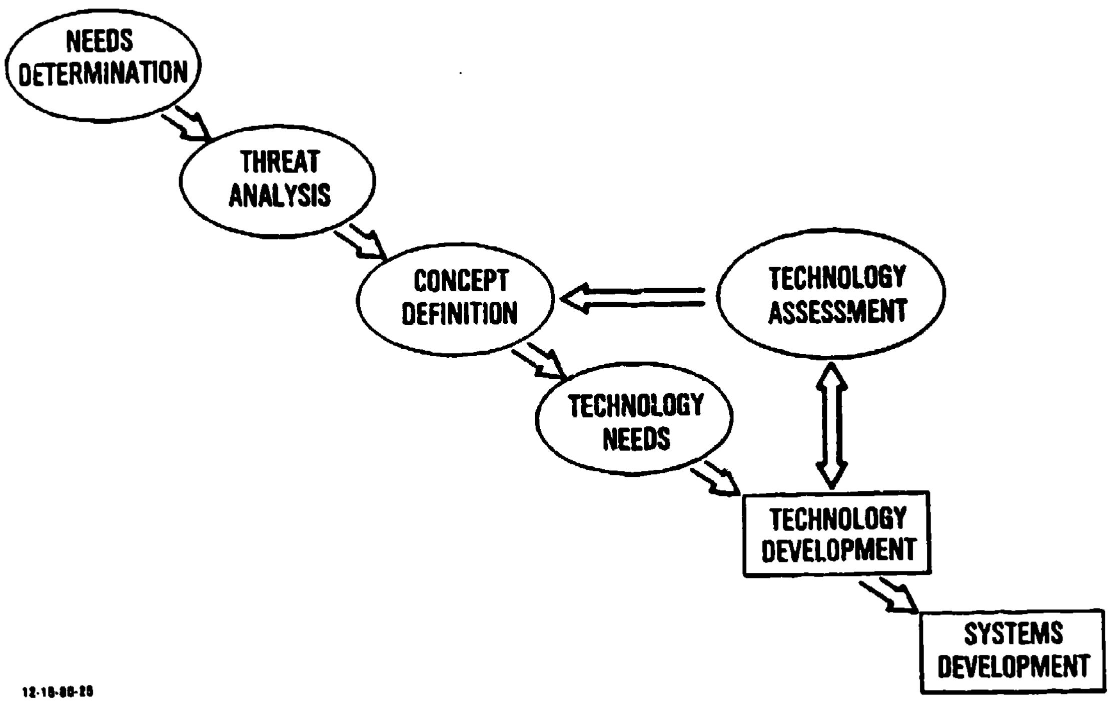

FIGURE VI-3. Technology Planning Method (Courtesy SD)

APPENDIX

SPACE LAUNCH COSTS

APPENDIX

SPACE LAUNCH COSTS

With the advent of the Shuttle imminent, it is of interest to update a previous (1972) determination (IDA, 1973) of the comparative launch costs of the Shuttle and expendable launch vehicles. This appendix summarizes the latest data (NASA, 1980b and Aerospace, 1980b) on launch costs in terms of tabulations, a comparative plot, and growth ratios from 1972 to 1980.

Shuttle Costs

While there existed a previous estimate of the Shuttle launch cost ($10.5M in 1972), the first estimate used in pricing policy negotiations between NASA and DoD was one derived in 1976 for the average cost of the first six years of a 572-flight mission model and quoted in 1975 dollars. The most recent revision of this estimate was made in 1979 based on the first six years of a 487-flight model and quoted in 1980 dollars. A tabulation of the component costs to the general user for these two estimates (from Aerospace, 1980b) is given below:

		SIX-YEAR AVERAGE COST	
Component	Estimate date:	1976(1975 $M)	9(1980 $M)
ET(O_2/H_2 not included)		3.84	8.79
SRB(propellant included)		4.46	8.77
SSME		0.35	0.54
Orbiter Spares		0.48	0.78
Crew Equipment		0.26	0.32
Contract Administration		0.17	0.33
		9.56	19.52
ET/SRB prefunding		- 0.40	
		9.2	
Risk Factor		3.0	?
		12.2	

The 1979 analysis then shifted its base from a six-year average to an average over the whole 487-flight model, and the \$19.52M figure became \$20.4M, with the assumption that there would be enough Orbiters (seven) in the fleet for the Shuttle to carry all the traffic. After the presidential decision to fund only four Orbiters, calculations for a reduced Shuttle flight-rate capability indicated an increase in the per-flight cost. The resulting costs per flight including operations are tabulated below (again from Aerospace, 1980b), for the average over that part of the mission model that each Orbiter fleet was assumed to be able to carry:

		OVERALL AVERAGE FLIGHT COSTS (1980 \$M)	
Component	Launch Site:	KSC	VAFB
"Consumables"		20.4	20.4
JSC Operations		5.1	5.1
Launch-site operations (incl. liq. prop.)		7.9	23.6
	7 Orbiters	33.4*	49.1
	4 Orbiters	35.2	52.3

*\$33.1M, per NASA quote to commercial users as of July 1980. Civil U.S. government charge would be \$4.3M less.

The \$35.2M figure is selected here to represent the Shuttle cost for delivery of 65,000 lb into the reference orbit at 100-nmi altitude and 28.5-deg inclination. The reason for the disparity in launch-site operations costs between KSC (\$7.9M) and VAFB (\$23.6M) is not currently known but is being actively investigated by Aerospace (Aerospace, 1980b). If the \$7.9M figure is revised upward, the \$35.2M total will increase accordingly. The marginal cost of one more military launch (at either site) would be the \$25.5M plus liquid propellants excluding other launch-site operations costs obtained by dividing the annual cost of launch-site maintenance by the nominal number of flights per year.

Expendable Launch Vehicle Costs

Estimates of the launch costs of expendable vehicles (ELVs) were obtained from NASA (NASA, 1980b), for NASA launch vehicles, and Aerospace (Aerospace, 1980b), for both NASA and USAF launch vehicles. The following table summarizes the estimates:

ELV LAUNCH COSTS (1980 $M)

Launch Vehicle or Stage	Source: NASA	Aerospace
Scout	~ 5-7	~ 1 (launch only)
Delta 3910	~ 22	~ 22
Delta 3920	~ 25	~ 30
T34D Core	-	~ 35
Atlas/Centaur	~ 38	52.3 (3 + option for 6)
T34D	-	~ 70 (6 per year)

IUS (2-stage)	~ 38	21.2
PAM-D	3.0	3.0
PAM-A	3.6	3.6

The ELV costs are highly dependent on the assumed launch rate and whether the buy will close out the production line. Hardware unit cost estimates for the T34D vary from about $70M to about $40M for buys from 3 to 6 per year (rates not less than previous Titan experience). Likewise, the pad maintenance costs, approximately $100-150M per year (no specific estimates were supplied), must be spread over the number of launches. If a contractor envisions termination with a buy, an increment of as much as $15M per unit may be applied. Because of these factors, few of the ELV launch-cost figures can be viewed as hard; only the Atlas/Centaur buy by Intelsat represents hard data.

The 1972 (IDA, 1973) and 1980 launch-cost estimates for the different launch vehicles are plotted against payload weight inserted into a reference 100-nmi, 28.5-deg circular orbit in Fig. A-1. For the ELVs, each time a payload exceeds the capability of a launch vehicle, the launch cost jumps to that for the next larger vehicle. The Shuttle pricing policy for partial payloads sharing the cargo bay is represented by the diagonal line going from 75 percent load factor to 5 percent for a constant cost-per-pound over that range. For high orbits, the IUS cost ($21M) would be added to both the T34D and the Shuttle.

For five of the launch vehicles, a "cost-growth ratio," the ratio of the 1980 cost to the 1972 cost, can be calculated. The following table gives that value:

Launch Vehicle	1980$/1972$
Scout	7/2.6 = 2.7
Delta 3910/2910	22/5.6 = 3.9
Atlas/Centaur	52/12 = 4.3
T34D/Titan III D	70/18 = 3.9
Shuttle	35.2/10.5 = 3.4

It is worthy of note that the Shuttle "cost-growth ratio" is comparable to (and not significantly larger than) those for expendable launch vehicles. However, all of these ratios are greater than those experienced in the same period by military procurement or O&M (both 1.8), Ref. (USAF, 1980).

A cost growth by a factor of 3.5 from 1972 to 1980 can result from an annual escalation of 10 percent from 1972 to 1976 and an annual escalation of 24 percent from 1976 to 1980, as an example.

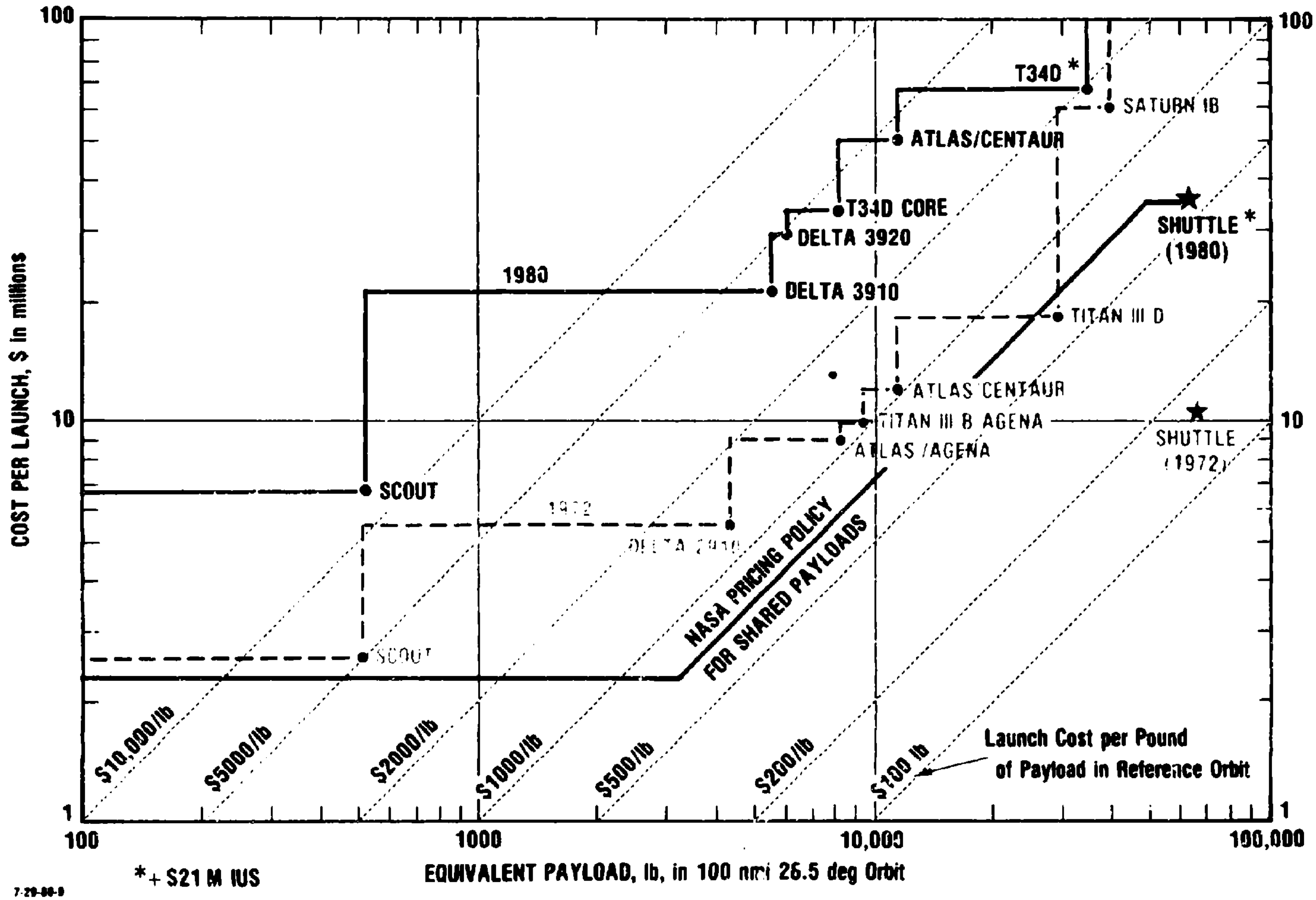

FIGURE A-1. Launch Cost as a Function of Payload Weight

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